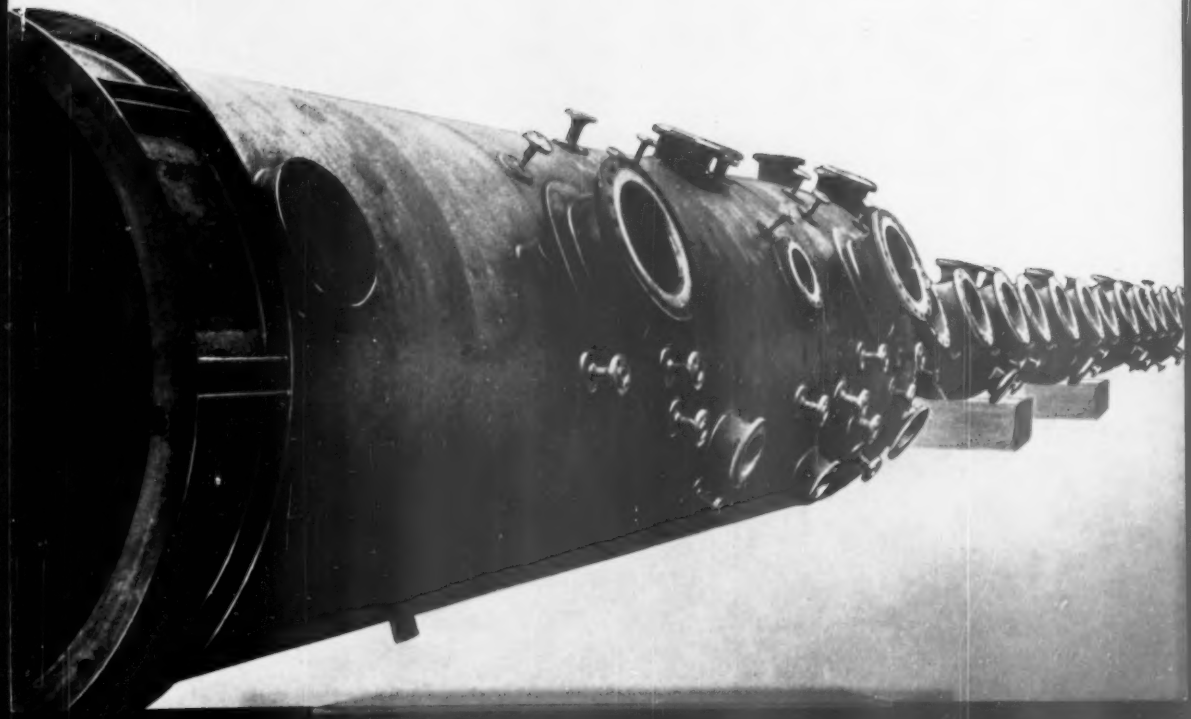
JUNE, 1950

The WELDING JOURNAL

Official Publication of the American Welding Society



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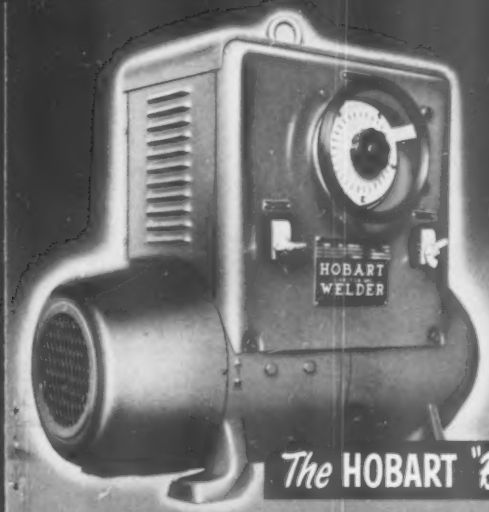

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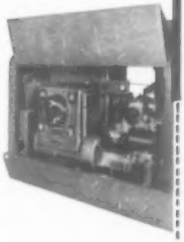

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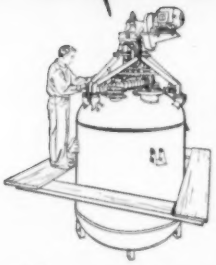

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cover: Welded Monel and Monel Clad atmospheric stripper and accumulator column 76 ft. 10 in. long weighing 41,500 lb. *Courtesy Downington Iron Works, Downington, Pa.*

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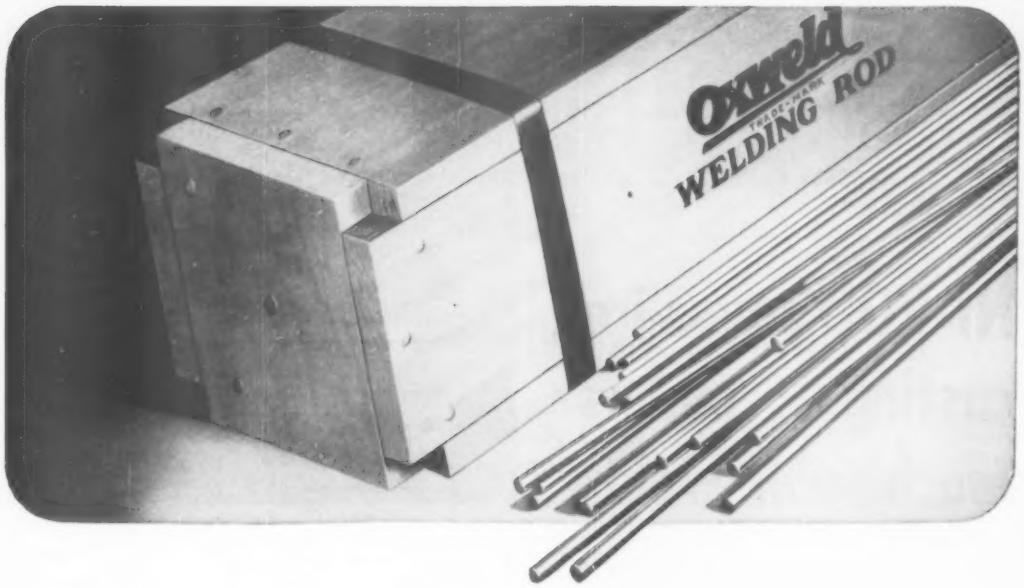

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The WELDING JOURNAL

volume 29 June 1950 number 6

Welding of Zinc Base Alloy Die Castings

Die casting has become an accepted engineering material under scientific control. Welds in this type of material can also be relied upon if the proper procedure control is followed

by Roland H. Ogden

THE earliest use of die castings was confined almost entirely to the manufacturing of toys and items for ornamentation. This was due, in part, to the poor physical properties of the product. Through the cooperation of machine tool engineers, metallurgists, product designers, and the die casting engineers the product of the die casting industry has become a widely used medium for the translation of ideas into material form. The acceptance of zinc base alloy die castings for highly stressed functional parts has become so widespread that few people realize, and relatively few engineers are aware of, the extent to which they are now used.

To mention a few of the many uses to which die castings have been applied we see such diverse items as typewriter frames, aircraft instrument parts, railroad signal devices, toys, machine tool frames, gears, automobile parts, and food mixers. We must not forget to mention that most important functional article—the zipper. It does seem a little incredible that so many uses have been found for a medium that appeared to have so little promise such a short while ago.

The reason that so much faith is placed in die castings today is because ways have been found to overcome the shortcomings of previously used methods and alloys. Your life, and mine, is protected and made more enjoyable by vital equipment fabricated in part, at least, from die castings. Obviously with so many castings being used in vital places we ask "what changes have been made in alloys and methods to make such a widespread acceptance come about?" Therefore let us consider the question for a moment.

Roland H. Ogden is President of the Alladin Rod and Flux Mfg. Co., Grand Rapids, Mich.

Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

When the industry was in its infancy the product was of inferior quality. The metal was "brittle," i.e., it lacked impact strength. The tensile strength was low and little or no elongation was to be expected. Only castings of relatively simple design could be made. In contrast to this we can now obtain castings wherein the impact, tensile and elongation values exceed those of good quality cast iron. The industry is producing castings of the most intricate design and complex coring. Die castings can be had weighing as little as those which make up a zipper to the recently announced die casting measuring 33 by 43⅜ in. and weighing upward of 10 lb.

A proper question to ask at this time is "what has all this to do with welding and of what value is it to the welder economically?" In answer to the question we should consider the facts and then take action in the direction which will lead to the mutual advantage of the welder and the user of die castings. It appears to be obvious that when a material is used to manufacture structural details and these parts are placed in service, failures will occur. Failure may be caused by faulty design, imperfect workmanship, abuse or a number of other reasons. It also appears reasonable to expect that as more and more parts are made and put into service more failures will take place. It is not axiomatic, however, that the percentage of failures will rise. On the contrary the percentage of failures will decrease because the designers will have gained experience in the use of the material. Suppose failure of a functional part takes place in a zipper or a machine part. Now we are not going to suggest that you attempt to weld up a zipper; that sort of repair work can well be left to other artisans. We are suggesting, however, that gears, machine parts, and a host of other functional details do fall within the welders province. A welding shop applying the proper techniques can make satisfactory repairs on zinc base alloy die castings.

Table 1

	Alloy No.					
	1	*2*	*3*	*4*	*5*	*6*
Commonly used domestic and foreign names	Zamak 2 A.S.T.M. XXI S.A.E. 921 Mazak 2 Gomak 2 GM-4128-M	Zamak 3 A.S.T.M. XXIII S.A.E. 903 Mazak 3 Gomak 3 GM-4130-M QQ-Z-363	Zamak 5 A.S.T.M. XXV S.A.E. 925 Mazak 5 Gomak 5 GM-4129-M QQ-Z-363	Zamak 6	Zinc base Slush casting alloys	Zinc base Slush casting alloys
	Composition, %					
Aluminum	3.5–4.5	3.5–4.3	3.5–4.3	4.10 nom.	4.50–5.00	5.25–5.75
Copper	2.5–3.5	0.10 max.	0.75–1.25	1.25 nom.	0.20–0.30	0.10 max.
Magnesium	0.02–0.10	0.03–0.08	0.03–0.08	Not spec.	None	...
Tin	0.005 max.	0.005 max.	0.005 max.	Not spec.	0.005 max.	0.005 max.
Lead	0.007 max.	0.007 max.	0.007 max.	Not spec.	0.007 max.	0.007 max.
Iron	0.100 max.	0.100 max.	0.100 max.	Not spec.	0.100 max.	0.100 max.
Cadmium	0.005 max.	0.005 max.	0.005 max.	Not spec.	0.005 max.	0.005 max.
Nickel	0.050 max.	0.050 max.	0.050 max.	Not spec.	...	...
Pd-Cd-Sn	0.010 max.	0.010 max.	0.010 max.	Not spec.	...	...
Zinc	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

That the idea is still prevalent among welders that white metal or, more properly, zinc base alloy cannot be welded is not too surprising. When one considers the dearth of information in the literature there can be no doubt about why the technique of making satisfactory welds in diecast material is practiced to such a limited extent. A search of the literature published in the German, French, Russian and English languages brings to light less than 15 papers on the subject to date.[1–6] In contrast to this, an article by Spraragen and Claussen[7] covering the period up to June 1, 1939, lists 124 references relative to the welding of the light metals. The literature covering the welding of light metals has grown considerably since 1939.

Getting back to the welding of "white metal," if a part breaks it has to be repaired or replaced. Sometimes, through obsolescence, the part cannot be replaced. Welding offers the ideal way of repairing the fractured casting. The pitfalls that beset a person who attempts to solder a die casting are too well known to be reviewed to any extent here. Suffice it to say that even though the parts are fastened together by soft soldering the strength of the whole will be very deficient, probably to the extent of being useless. Welding, properly done, will leave the parts as strong structurally as they were when made. The castings can be given the same finish as they were given at the time of manufacture. It is reasonable to expect that, after welding, the castings will give just as good service and as long life as a new part.

Before a successful weld can be made in any material some knowledge must be obtained concerning the composition of the base metal and of the welding rod that is to be used. Table 1 shows the chemical composition of six of the zinc alloys most used by industry today. The compositions shown probably cover 98% of the metal used by the die and slush casting industry in this country and abroad. Of the six alloys listed only two find widespread use at the present time. Alloys listed under the second and third paragraphs of this article have the greatest use with No. 1 alloy finding use for special purposes and to a limited extent.

The composition of a well-known welding rod used in the welding of zinc base alloy die castings is shown in Table 2. It will be noted that this analysis conforms very closely to that of Alloy 1 shown in Table 1.

Table 2

Element	*Composition, %*
Aluminum	4.15
Copper	2.97
Magnesium	0.045
Tin	0.001
Lead	0.002
Iron	0.045
Cadmium	0.002
Antimony	Nil
Zinc	Remainder

Experience shows that certain advantages are to be obtained by the use of the alloy shown in Table 2. This alloy, a ternary alloy, tends to be finer grained under the blowpipe flame. As will be noted from the analysis this alloy is almost of the composition called for by the ternary eutectic.[8] Such an alloy has the lowest melting temperature of any possible combination of the three major constituents. With a liquidus temperature of approximately 707–710° F.[8] we can, with some reasonable assurance, expect complete fluidity of the filler metal when the base metal is at the mushy stage. We are assuming, of course, that the casting metal has a solidus of 716.7–717.1° F. and a liquidus of 727.0–727.9° F.[9] Sober thought will tell us that normal variations in composition are to be expected in both the base metal and the filler rod. With the metal having these variations in analysis an allowance should be made for a deviation from the theoretical melting points. By exercising every possible precaution during the melting and alloying of the filler rod metal the composition is held to a very narrow range of variation. This care is taken for the expressed purpose of obtaining as stable a melting point as possible. In this way the gap between the melting points of the base and filler metals is kept as wide as possible. Repeated tests on various heats of metal alloyed for making welding rod, using calibrated thermocouples and potentiometers, indicate

Figure 1

a melting point spread of approximately 5° F. Such a small range is thought to be quite unusual.

It must be recognized that there will be cases where the base metal will have the same or almost the same melting point as the rod being used. When this condition exists some support under the weld must be provided. As the welder will never know when he is going to run into this situation he should always provide the support before he starts applying the blowpipe flame to the work. In applying any theoretical figures relative to melting points to practical problems we must use caution and be alert to the unexpected. In this way many pitfalls and failures will be avoided.

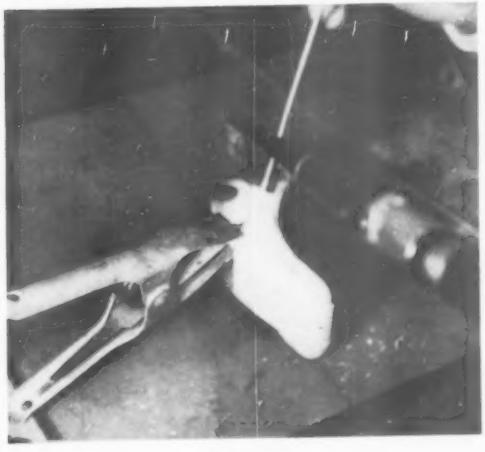

Figure 2

Metallographically we are fortunate in that the component constituents arrange themselves, under the influence of heat, in such a way that the low melting eutectic is formed first. They also use up all of the available elements to form the maximum amount of this eutectic. This property of metals makes it possible to get the homogeneity evidenced in the photomicrographs shown in Figs. 3 and 4. These photomicrographs were taken of structures obtained when the commercial die casting shown in Fig. 1 was welded under ordinary shop conditions. The part illustrated is a refrigerator door handle detail. Particular attention should be given to Fig. 3. This photomicrograph, taken at a magnification of 100 diameters, indicates that the line of demarkation between the weld metal and the base metal is hardly discernible. The only effect noticeable is a slightly smaller grain size in the weld metal and a decrease in porosity. The larger white areas are the solid

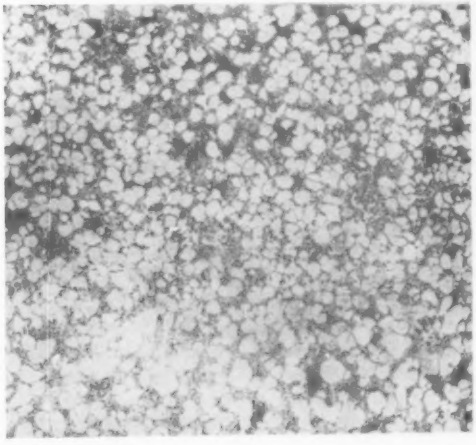

Figure 3

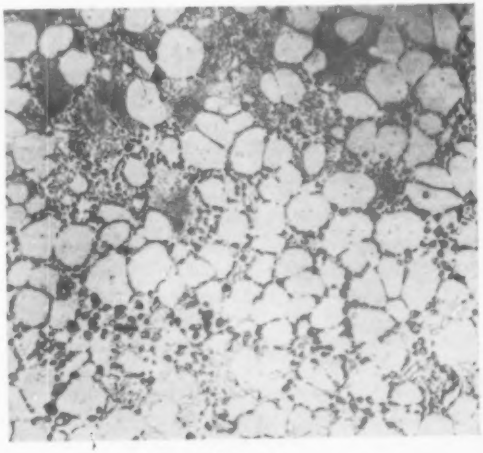

Figure 4

solution constituent and it is more prevalent in the parent metal as is to be expected from its analysis. The ternary eutectic, which is the feathery looking stuff is very much more pronounced in the weld metal. Figure 4, taken at 500 diameters magnification, shows the eutectic quite clearly.

Getting down to the actual mechanics of making the weld we have to face certain facts. First the temperature range within which we must work is rather narrow. The range amounts to about 18 to 20° F. The nature of the alloys are such that if the temperature throughout the casting approaches the liquidus, the whole casting will collapse into a pool of molten metal. The alloys used to make die castings are, fortunately, relatively poor conductors of heat. The volume conductivity relative to copper being approximately 27%.[9] Die-casting alloys are prone to the formation of tough tenacious oxides when subjected to elevated temperatures; a property which can be both advantageous and exasperating.

Using the various properties both advantageous and perverse together with some ingenuity we can bend them all to our will. Starting with that property of the alloys having a melting range rather than a sharp melting point, we are able to tell when the parent casting metal is at the proper temperature to start welding. The trick is in looking for the first molten metal which appears on the surface.

To keep the whole casting from collapsing, advantage is taken of the heat conductivity of the casting alloy. By combining this property of poor heat conductivity with flame manipulation we can more or less control the heated zone.

The formation of a tough tenacious oxide film is made to work for us through its tendency to support the mushy metal during the welding process. The oxide film must, however, be punctured by the filler rod and must be removed from the immediate vicinity of the molten metal in the weld zone or porous welds having areas of incomplete fusion will result.

The preparation of the casting at the point of failure for welding is of prime importance. All foreign matter of any origin must be removed. This matter may consist of chrome or nickel plating, paint, grease, oxides or any number of other things. Preparation of the surface may be accomplished by grinding, filing, dissolving with suitable solvents or by other expedients. After the casting is cleaned the break is vee'd out to an included angle of 45°. The vee should extend all of the way through the casting under all normal circumstances. The prepared edges are then scratch brushed.

If the casting is large and complicated preheating to approximately 240° F. of the whole structure is recommended.[1] We must remember that the zinc alloys have a rather large coefficient of expansion and any localized heating may well cause serious distortion.

Consideration of the adjustment of the blowpipe flame should occupy our attention. As we are already cognizant of the propensity of the zinc die-casting alloys to form oxide films at relatively low temperatures, means of combating their formation have to be considered. The most obvious method, and the most useful, is to make use of the blowpipe flame. To prevent or at least help prevent the formation of oxides we must have a reducing flame. A protective flame that is chemically reducing in its action on molten metal is produced by using an excess of acetylene. A soot forming condition must be avoided at all times, however. Experiments indicate that the correct adjustment is had when the inner cone is white and slightly bushy. The use of a No. 1 or No. 2 tip is recommended as adequate for most jobs. A larger tip may be required when repairs are being made on large Kirksite die blocks or work of a similar nature. It is well to remember that the metal when at the correct temperature for welding is weak and without much strength. Therefore a soft lazy flame is to be preferred over one which is noisy and of high velocity. The latter type of flame is likely to blow through the metal being worked upon. A pressure at the gages of 2 lb. of oxygen and 4 lb. of acetylene appears to be about right. At times a slightly higher oxygen pressure may be required to remove the sooting tendency of the flame.

With the work suitably supported, the flame in adjustment, any preheating that may be required taken care of, and a supply of welding rod at hand, welding is started. The blowpipe flame should be applied to the work in such a manner that a small spot is heated until the metal begins to flow. The blowpipe is now turned sideways in a manner as to cause the flame to be almost parallel to the line of weld in both the vertical and horizontal planes. Remembering that thin oxide coating over the molten metal, the end of the filler rod is thrust through the film covering the base metal. In this way and by a continual puddling action with the end of the rod the filler metal may be made to flow into the weld. The method of flame adjustment and manipulation relative to the welding of die castings and "white metal" is covered in a U. S. patent.[10]

To make use of another property of zinc alloys, that of the mushy stage, a small spatula made by hammering out the end of a steel or, preferably, tobin bronze welding rod and suitably rounding is required. The mushy-stage property is useful when building up bosses, square edges and around holes to give a few examples. To do this building up or shaping we must first of all build up a mass of metal around the place we wish to enlarge or shape. In doing this the surface tension and the oxide film will tend to make the mass of metal take on a rounded contour. By heating the whole mass to the temperature where it is just mushy or, to be technical, just above the solidus, we can shape or trowel, if you please, the metal into the shape or form that is desired.

By careful attention to detail the broken part should now be ready to be returned to service except, possibly, for some machining or refinishing. By depositing an excess of metal on the weld the surface can be dressed down by filing, grinding, machining or other method so

that a smooth even profile will result. After preparing the surface to match the surrounding area the part can be refinished exactly as the original finish was applied.

Summing up the pertinent points:

1. Clean the metal around the failure very carefully, removing any plating, paint or grease.

2. Vee out the metal to an included angle of approximately 45° along the line of fracture where the weld metal is to be deposited.

3. Careful attention should be paid to the adjustment of the blowpipe flame. A soft hazy flame is best for successful welds.

4. Apply the blowpipe flame to the work properly. By proper manipulation of the flame and the relatively poor conductivity of the base metal rather good control of the weld zone temperature may be exercised.

5. Apply the welding rod in such a manner as to facilitate the flow of metal under the oxide film. The oxide must be prevented from being stirred into the weld zone.

6. Scrap material is wholly unsuitable for use as filler rods in the welding of white metal and its use can only result in inferior results.

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The Aircomatic Welding Process

Fundamentals of metal-arc transfer in inert-gas-shielded arc welding are discussed. Methods of overcoming porosity in aluminum welding by automatic and manual welding as well as stainless steel, heat-resisting alloys, clad materials and aluminum bronze are covered. Half of the paper is devoted to specific applications

by A. Muller, G. J. Gibson and E. H. Roper

Part I—Fundamentals

INTRODUCTION

THE Aircomatic process may be defined as inert-gas-shielded metal-arc welding. A consuming electrode is used which differentiates this process in one respect from the inert-gas-shielded welding process which uses non-consuming tungsten electrodes. Fundamentally, the tungsten arc process simply provides a protected source of heat for fusing metals. Filler metal may or may not be added to the arc as an independent operation. The Aircomatic process is characterized by an inert-gas-shielded arc between the workpiece and a consumable electrode through which metal is transferred to the workpiece where it becomes part of the joint. The transfer of material through the protected arc column increases the efficiency of heat input to the workpiece over that obtained in the tungsten arc process. This increase in efficiency is partially the result of the heat content of the superheated metal passing through the arc. The resultant high intensity heat source permits very rapid welding.

Practical means for applying the Aircomatic process have been developed: one method employs a manually manipulated welding gun; another method uses an automatic head. Both methods use a continuously fed bare wire in coil form for the electrode. The inert monatomic gases are suitable for shielding; both helium and argon and mixtures of these gases can be used. The arc is shielded by a stream of gas which issues from a nozzle through which the electrode passes. The nozzle is positioned so that the gas stream shields the arc but does not impair visibility. Equipment for manual welding is shown in Fig. 1. The wire reel, feed motor and electrical controls are contained in the frame assembly. Wire and gas are carried to the gun through a flexible hose. The manual gun employs a small flexible electrode wire having a maximum diameter of $^3/_{32}$ in. With this arrangement the gun can be manipulated to weld in all positions. The automatic head is shown in Fig. 2. The distinguishing feature of this head is the gas nozzle assembly. The automatic head can be used only for flat or horizontal fillet welding. This apparatus can be fixed in position or mounted on a travel carriage as shown in the photograph.

The published literature relating to welding arcs with consuming electrodes in controlled gaseous atmospheres is meager. Except for the comprehensive investigations of Doan and associates,[1-7] the object of which was to study the influence of surrounding atmospheres on

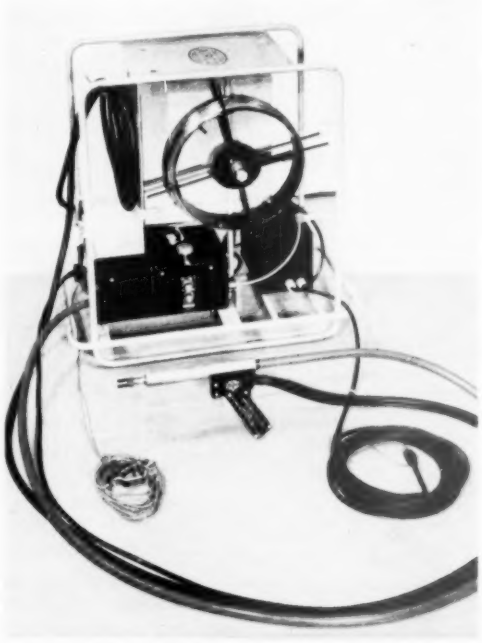

Fig. 1 The aircomatic gun

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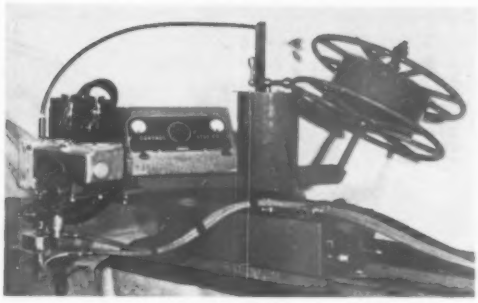

Fig. 2 The aircomatic head

fundamental arc characteristics and weld metallurgy, little has been done in this field. The above investigations involved welding in an enclosed chamber, and showed that welding arcs in inert gases were erratic, particularly when the electrode was positive. The metal transferred in very large drops, shallow or no weld penetration was obtained and no crater was present under the electrode. The presence of air in the arc had a profound effect on penetration, crater formation and the mechanical properties of the weld metal. In the present process effective gas shielding is obtained by a flow of inert gas from a nozzle and thus welding is not limited to an enclosed chamber.

CHARACTERISTICS OF THE AIRCOMATIC WELDING PROCESS

A description of the characteristics of this inert-gas-shielded metal-arc welding process contributes to the knowledge of fundamental arc-welding phenomena. This welding method is basically one of the simplest of all metal-arc welding processes. Bare filler wire is melted in a completely inert atmosphere and is efficiently transferred to the joint where the arc provides sufficient heat to fuse the plate surfaces to make an effective junction. In all other metal-arc welding processes the metallurgy and arc phenomena are complicated by slag-metal and gas-metal reactions at high temperatures from the time the metal melts off the end of the electrode until it freezes in the joint. Arc action is complicated by dissociation and subsequent recombination of polyatomic gases present in the arc. No fluxes are required with the inert-gas-shielded arc because the electrical cleaning action associated with reverse polarity welding current usually employed for this process effectively removes the surface oxide film from the joint.

Metal transfer in the inert-gas-shielded metal-arc is very efficient. Chemical analyses of the electrode wire and deposited pads of undiluted weld metal are practically identical for all the common metals and alloys. Zinc is the one important element that is not satisfactory for welding because of the high vaporization loss occasioned by its low boiling point and detrimental effect on arc action. Even the very active element titanium may be recovered in the weld with fair efficiency when present as an alloying element in the electrode wire.

The most impressive feature of this inert-gas-shielded metal-arc process is the mechanical transfer of metal from the electrode to the weld. The principal requirement for this desirable type of metal transfer is high electrode current density. At a certain minimum current density which varies with both electrode size and material, transfer through the arc changes from very large globular drops which fall off the end of the electrode to a spray of extremely fine droplets which is projected from the end of the electrode in the direction in which the electrode is pointed. At this point the arc changes from a fluttering erratic discharge with wandering cathode spot to a steady quiet column. This arc column has a well-defined narrow incandescent cone-shaped core within which the metal transfers. Two photographs of this arc are shown in Figs. 3 and 4. These pictures show that the direction of the inner cone and metal transfer follow the direction in which the wire is pointed. These photographs also show a complete absence of spatter particles which is another desirable characteristic of the process for some materials.

The projected metal transfer which occurs in this process makes vertical and overhead welding possible. The mechanism of metal transfer for overhead welding has been extensively discussed in the welding literature. The accepted explanation has been that expansion of gases at the tip of an electrode has provided the primary force to project metal across the arc, and that overhead welding with killed steel and "gas-free" core wires is very difficult or impossible without this phenomenon. However, with this process, overhead welding is easily effected with aluminum, killed steel, stainless steel and other essentially gas-free metals. In searching for an explanation for this projected metal transfer in a high-current density arc it has been necessary to reconsider early theories on the "pinch effect"[1, 9] which have been largely discredited in the more recent literature as a major factor in metal transfer. It has been pointed out that the effective electrical forces of the "pinch effect" are not large enough to overcome the weight of the relatively large molten droplets formed on the end of con-

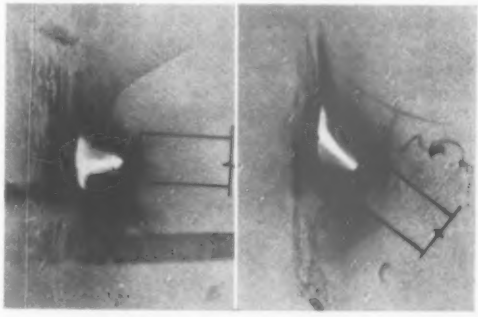

Fig. 3 (Left) Photograph of arc with the gun in a horizontal position
Fig. 4 (Right) Photograph of the arc with the gun pointed upward at a 45° angle

ventional sized electrodes. The magnitude of propelling forces of the "pinch effect" is a function of the square of the welding current which in this process is in the same order of magnitude as generally used for over-head welding with coated electrodes. This force apparently is sufficient to transfer the smaller droplets formed at the end of a small diameter wire operated at high current density. For example, the threshold current for projected metal transfer is about 140 amp. for $^1/_{16}$-in. diameter aluminum electrode. At 120 amp. large drops grow on the end of the electrode which fall off at a rate of about 3.6 per second. Each drop represents about $^5/_8$ in. of melted wire. Oscillographic studies of arc voltage and current have been made to determine drop interval. The results indicate that the projected transfer involves a succession of discrete droplets of uniform size for any given current. At a current of 140 amp. the transfer changes rather abruptly so that all the metal will transfer through a $^1/_4$-in. horizontal arc and be deposited on a vertical plate. At this current the droplets travel through the arc at a rate of 34 per second with 0.07 in. of wire contained in each droplet. At 160 amp. the transfer rate is 49 per second with 0.05 in. of wire in each drop. At 140 amp. these drops are visibly discernible in the arc but at 160 amp. they cannot be distinguished.

The problem of lack of weld penetration which was noted in early investigations has been solved with the development of this process. Even in the low range of welding currents the use of high-current density establishes a stable-arc column with a well-defined cathode spot on the workpiece so that the work is always fused where metal is deposited. The photographs of the arc in Figs. 3 and 4 illustrate the narrow stable arc core which concentrates heating at a localized region of the workpiece. This particular property permits the making of fully fused small fillet welds in relatively heavy material and the building-up of butt welds in narrow grooves. The amount of penetration for a given current can be controlled by arc length and the choice of shielding gas. At the same current and arc length, arc voltage is higher with helium shielding than with argon and the resulting increased energy with helium produces deeper penetration. This has advantages for welding high conductivity metals such as aluminum and for making small welds in other metals. Argon has advantages in that the arc is usually smoother with less spatter and is more desirable for welding where minimum penetration is required.

The presence of a crater under the arc is not necessary for obtaining adequate penetration with this process. In the lower current range up to about 200 amp. the presence of a crater is not particularly noticeable. However, at currents in the 600-amp. range, particularly in aluminum, the craters are as much as $^5/_{16}$ in. in depth. Craters are also present in steel welding. Craters are apparently caused by the pressure from the arc and their size is primarily a function of current and the material being welded.

Another very interesting phenomenon associated

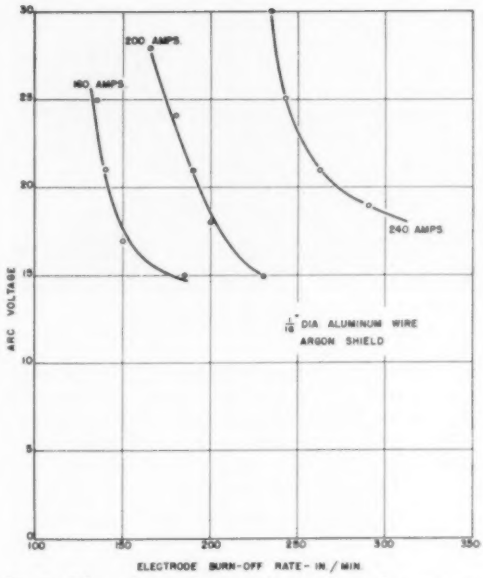

Fig. 5 Effect of arc voltage on burn-off rate for constant current

with inert-gas-shielded arcs of high-current density is the effect of arc voltage on the burn-off rate of the electrode. This relationship is shown in the chart of Fig. 5. This chart shows a very substantial decrease in burn-off rate with increased arc voltage for constant current. A possible explanation for this occurrence is that with long arc lengths much less radiant energy is absorbed by the end of the electrode. This particular characteristic together with rapid electrode wire feed rates and the drooping current-voltage characteristics of conventional d.-c. welding generator sets makes possible a simple method of arc length control. When a proper arc is established it is automatically maintained without further adjustment. The self-regulating characteristics of the process automatically compensate for changes resulting from unevenness in the work or unsteadiness of the operator. The wire feed speed for proper arc length remains constant irrespective of what occurs at the welding arc. Accidental changes resulting in an increase in arc length increase the arc voltage. This is accompanied by both a decrease in welding current and burn-off rate resulting from this reduced current and a further decrease in burn-off rate resulting from the increased arc voltage as indicated in Fig. 5. The balance between feed speed and burn-off rate is upset and the arc shortens to its original length. Conversely, the opposite happens if an accidental change occurs which decreases the arc length. This inherent self-regulation makes the process essentially automatic. This method of control is not sensitive to variations in torque required to feed the wire and cannot "hunt" because mechanical inertia is not involved. A detailed analysis of the self-regulation phenomena is beyond the scope of this presentation.

Most of the characteristics of Aircomatic welding which have been described pertain to the operation of the manual gun in which they are used to maximum advantage. The same principles may also be used for mechanically controlled welding operations where the gun or its equivalent are fixed in position. However, for applications requiring 400 amp. or more and for wire sizes greater than $^3/_{32}$ in. a conventional type of automatic head is preferred. Since welding with the automatic head is limited to the flat position it is not essential to employ current densities that will give projected metal or spray transfer although this is usually desirable.

Summarizing, this inert-gas-shielded metal-arc welding process possesses certain unique arc characteristics which gives this process many advantages over other methods of welding which include simplicity of control, speed of welding, and deposition efficiency. In addition the process is applicable to a variety of metals heretofore considered difficult to fabricate.

ALUMINUM

The Aircomatic process was first applied to the welding of aluminum. The simple strain-hardening alloys such as 2S, 3S, 4S and 52S as well as the magnesium silicide type age hardening alloy, 61S, can be welded. Other high strength precipitation hardening alloys containing copper and zinc are not considered readily weldable and have not yet been investigated. The electrode wire compositions available for welding are commercially pure aluminum, 2S, and 5% silicon alloy, 43S. The commercially pure aluminum wire is used for welding the 2S, 3S and 4S alloys and the higher strength 5% silicon wire is used for the higher strength alloys.

Aluminum welding with this process is simple and straightforward. Chemical analyses of wire and undiluted weld pad deposits are practically identical as shown in Table I. When a weld is made in a joint the alloys present in the fused area of the base metal appear in the weld metal. This mixing improves the strength of 2S weld metal in the case of welding 3S plate. When 61S plate is joined with 43S wire the resulting weld metal analysis responds to the standard heat treatment for 61S material and is considerably strengthened by this operation. The degree of alloying depends on the relative amount of base metal melted for the amount of filler metal added. The degree of mixing can be controlled by joint design and welding procedure.

Table I—Chemical Analyses of Aluminum Electrode Wire, Plate and Weld Metal

	Element, %					
Samples	*Al*	*Si*	*Cu*	*Mn*	*Cr*	*Mg*
2S Wire	99.2	0.19	0.10			
Weld pad from same	99.2	0.19	0.12	0.01		
43S Wire	94.9	4.57	0.08			
Weld pad from same	95.1	4.45		0.01		
43S Wire	94.5	4.98		0.04		
Weld metal of joint in 61S plate	96.2	2.59	0.10	0.05	0.11	0.48
Nominal composition of Al alloys						
2S	99 min.					
3S	Bal.			1.2		
4S	Bal.			1.2		1.0
43S	Bal.	5.0				
52S	Bal.				0.25	2.5
61S	Bal.	0.6	0.25		0.25	1.0

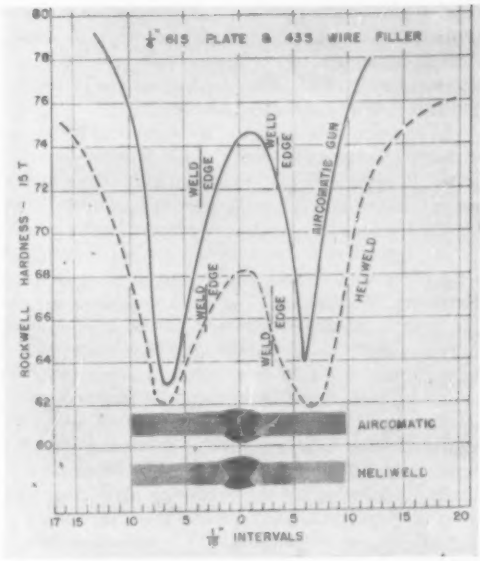

Fig. 6 Comparative hardness traverses of aluminum butt welds made with the aircomatic and tungsten-arc processes

Another characteristic of this process which is advantageous from a metallurgical standpoint is the rapid rate at which metal is deposited. The intense heating and rapid travel speed results in a narrower heat-affected region than is obtained with the tungsten arc process. Figure 6 shows macrosections of two square butt joints made in $^1/_4$-in. 61S-T6 plate using 43S wire; one plate was welded by the Aircomatic process and the other by the tungsten arc process. Hardness traverses across each joint show that the over-aging effect in the heat-affected zone is less for the Aircomatic weld both in degree and extent.

There is a phase of the metallurgy of aluminum welding which presents a problem which is difficult to control. This problem involves the causes and methods for eliminating porosity in aluminum welds. Hydrogen has long been known to be troublesome in aluminum foundry practice in causing porosity in castings. Hydrogen is also believed to be principally responsible for porosity in aluminum welds. Hydrogen from any source readily dissociates in the arc. The resulting atomic hydrogen is highly soluble in molten aluminum, but practically insoluble in pure aluminum in the solid state. When molten aluminum weld metal containing hydrogen in solution cools to the solidification temperature, the hydrogen contained in solution is rapidly rejected forming bubbles which tend to escape from the surface of the freezing metal. If the cooling rate is rapid, which is a characteristic of this inert-gas-shielded

metal-arc welding process, some of the escaping gas may be trapped forming spherical gas pockets in the weld. Vacuum-fusion analyses of the gas extracted from porous weld samples have shown hydrogen to be present in sufficient amounts to account for porosity.

The complete elimination of hydrogen and hydrogen containing compounds from the arc is extremely difficult. Possible sources of hydrogen include the shielding gas, hydrocarbons on the wire or base metal, and adsorbed water vapor on the oxide film of both wire and plate. Tests have shown that the purity of argon and helium now commercially available for welding does not contribute to porosity. Complete degreasing of the wire prior to welding results in a marked improvement in weld porosity and the use of cleaned wire stripped of its oxide film still further reduces porosity. Water is contained in combination in the oxide film present on aluminum which has been exposed to moist air. This combined water usually is present either as a monohydrate, $Al_2O_3 \cdot H_2O$, or a trihydrate, $Al_2O_3 \cdot 3H_2O$, both of which dissociate in the arc producing hydrogen. The effect of cleaning the joint surfaces is not as marked as that of cleaning the wire because the effective surface area involved is much less than that of the small diameter wire used for welding.

The most effective method for control of weld porosity is by using a welding procedure and technique which promotes the escape of the gas before the surface of the metal freezes. In general this technique involves agitating the weld puddle to promote the elimination of gas bubbles. With proper technique and clean wire that has been protected from excessive atmospheric exposure, sound welds can be readily made in the flat position which are acceptable under pressure vessel standards. Elimination of porosity in vertical and overhead welding is more difficult because welding techniques are limited to those resulting in quick freezing of the weld metal so that it will not run out of the joint. Fortunately the welding procedures found best for eliminating porosity in the flat and horizontal position are not detrimental to weld appearance or production rates. A group of test specimens made to qualify the process for fillet welds for pressure vessel fabrication are shown in Fig. 7.

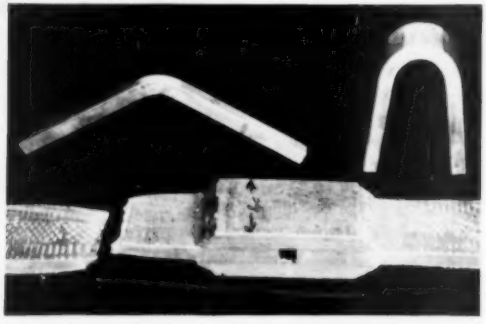

Fig. 7 Pressure vessel qualification test specimens, A.S.T.M., Part IX, Fig. Q-4 and Q-5

If no particular precautions are taken to make sound deposits, welds are obtained which exhibit excellent tensile properties and which are suitable for many applications. This is particularly true for fillet welds made with the manual gun. When the porosity is excessive the ductility and toughness of such welds are appreciably less than comparable sound welds.

Manual Welding

At present the range of the Aircomatic gun for weld-

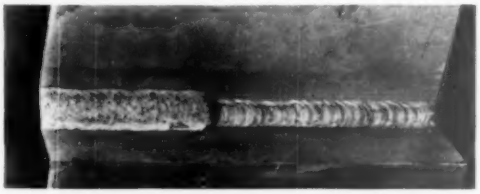

Fig. 8 Photograph of a 2-pass $^5/_{16}$-in. fillet weld in 1-in. aluminum plate made in the flat position

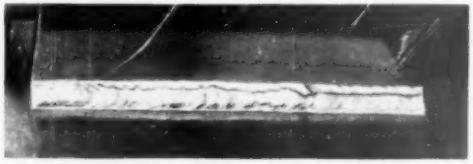

Fig. 9 Photograph of a single-pass, $^5/_{16}$-in. aluminum fillet weld made in the horizontal position

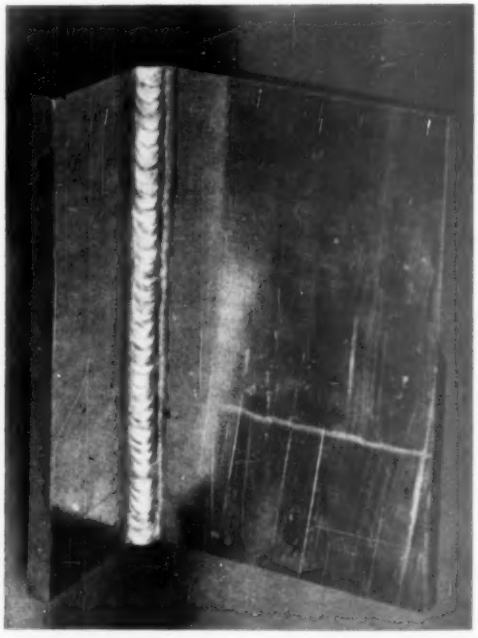

Fig. 10 Photograph of a $^5/_{16}$-in. aluminum fillet weld made in the vertical position

ing aluminum extends from a minimum of $^3/_{16}$ in. to the maximum thickness available. All types of commonly used butt and fillet joints can be made and the method is particularly adapted for welding in restricted regions which are impossible to reach with the tungsten arc process. Welds can be made in all positions—flat, horizontal, vertical and overhead. The gun is easy to operate and less skill is required to make acceptable welds in all positions than with coated-steel electrodes.

The process is particularly advantageous for making fillet welds. Attractive appearing fillets with good fusion and strength can readily be made at remarkably fast speeds. Typical examples of such fillets are shown in Figs. 8, 9 and 10. Fillet welds can be made at a speed of 4 ft. per minute but since a welder can usually make only about 2 ft. of joint without stopping and moving, such high speeds lose some of their advantage and it has been found desirable to limit manual welding speeds to 20 to 24 in. per minute.

Table II—Manual Welding Procedures for Aluminum and Aluminum Alloys

Plate thickness, in.	*Welding position*	*Wire diameter, in.*	*Gas flow—Argon, cfh.*	*Gas flow—Helium, cfh.*	*Current range, amp.*
$^3/_{16}$–$^1/_2$	F & H	$^1/_{16}$	20–40	30–50	160–250
$^1/_8$-up	F & H	$^3/_{32}$		50–75	225–350
$^3/_{16}$-up	V & O	$^1/_{16}$	20–40	30–50	140–225

The establishment of a welding procedure for a particular job involves a selection of wire size, current and gas flow. Table II may be used as a guide for this purpose. Helium is generally preferred to argon for shielding because better shaped and smoother weld beads are produced and the penetration is greater. There is less tendency for porosity when helium is used. It is sometimes desirable to mix 10 to 30% argon with helium to provide a smoother arc with less spatter. The proper welding current will provide the necessary root fusion and produce a weld with a good "layed in" appearance. Excess current makes manipulation of the gun more critical to prevent undercutting, burn through and poorly shaped welds. The correct arc length is important in eliminating porosity. A long arc length should be used; preferably between $^3/_{16}$ and $^1/_4$ in. long. In making small fillet welds and welding in narrow grooved butt welds, however, a $^1/_8$-in. arc length is preferred. A detailed description of welding technique is outside the scope of this presentation but in general the arc should be manipulated in a reciprocating fashion to secure the maximum amount of stirring action in the weld puddle which permits gases in the metal to escape.

Burn-off rates for $^1/_{16}$ and $^3/_{32}$-in. diameter aluminum wire are shown on the charts of Figs. 11 and 12. The burn-off curves are useful for establishing the initial wire feed speed rate when welding. These charts also indicate the melting rate of the wire for the current used. Deposition rates and production costs can be calculated from the charts by applying the appropriate wire loss factors. The loss factors are approximate and include spatter and vaporization losses. At the low

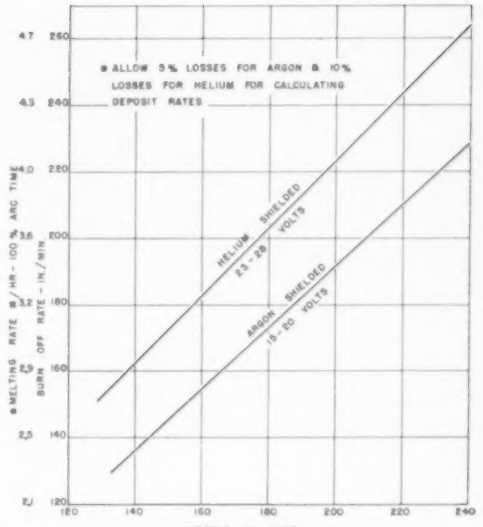
* ALLOW 5% LOSSES FOR ARGON & 10% LOSSES FOR HELIUM FOR CALCULATING DEPOSIT RATES
HELIUM SHIELDED 23 - 28 VOLTS
ARGON SHIELDED 15 - 20 VOLTS
* MELTING RATE #/HR - 100% ARC TIME
BURN OFF RATE - IN/MIN
CURRENT IN AMPS.

Fig. 11 Average welding rates, $^1/_{16}$-in. diameter 28 or 43S wire

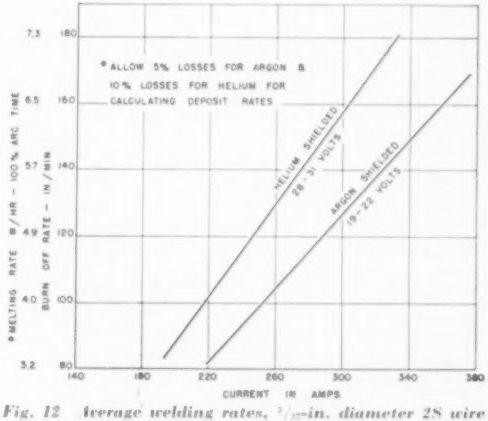
* ALLOW 5% LOSSES FOR ARGON & 10% LOSSES FOR HELIUM FOR CALCULATING DEPOSIT RATES
HELIUM SHIELDED 28 - 31 VOLTS
ARGON SHIELDED 19 - 22 VOLTS
* MELTING RATE #/HR - 100% ARC TIME
BURN OFF RATE - IN/MIN
CURRENT IN AMPS.

Fig. 12 Average welding rates, $^3/_{32}$-in. diameter 28 wire

range of current for a given wire size spatter losses are proportionately greater than at higher currents where the vaporization losses increase and spatter decreases. The black powdery deposit present on the surface of the joint after welding is aluminum vaporized in the arc and subsequently burned in the atmosphere outside the gas shield.

The mechanical properties of aluminum welds made with the manual gun are excellent. Shear strengths for fillet welds are indicated by the tests shown in Table III. The test specimens were cut from long double-tee test plates. A sectional view of one of these specimens is shown in Fig. 13. The two opposite legs of the tees were not always in exact alignment, being somewhat offset as well as bent, so that the tests may not represent the maximum shear strengths obtainable with standard specimens. The procedure data in the tabulation

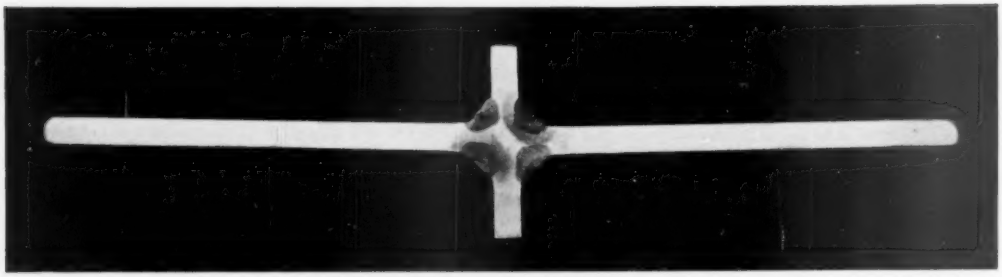

Fig. 13 Sectional view of a 1/4-in. thick fillet weld shear test specimen

TABLE – III

PROCEDURES AND SHEAR STRENGTHS OF FILLET WELDS MADE WITH THE AIRCOMATIC GUN

PLATE THICK. IN.	WELD POSITION	FILLET SIZE IN.	WELD CURRENT AMPS.	HELIUM FLOW CFH	WELD SPEED 100 % ARC TIME IN./MIN.	WELD SPEED 100 % ARC TIME FT./HR	BREAKING LOAD LBS./IN. AS WELDED	BREAKING LOAD LBS./IN. HEAT TREATED	SHEAR STRENGTH LBS./IN.^{2} AS WELDED	SHEAR STRENGTH LBS./IN.^{2} HEAT TREATED
1/4 61 ST 6	HORIZ	1/4	170	50	21	105	3080	3660	18 300	23 000
							3500	4340	22 000	24 400
							3490	5000	22 000	28 200
		3/16	190	50	32	170	2740	4040	19 600	22 600
							2550	4050	17 100	25 400
							2570	4140	17 300	26 000
	VERT	3/16	180	50	24	120	2640	3870	17 600	21 800
							3180	4180	20 000	26 200
							2870	4180	18 000	26 100
	OVER HEAD	7/32	170	50	26	130	3000	4330	21 600	23 000
							2670	3940	19 200	24 800
							2790	4020	20 000	23 800
1" 38 F	FLAT	1/8	350	75	18	90	5080		18 500	
							5440		19 000	
							5500		19 300	

1/8" 43 S WIRE USED FOR 61 ST 6 SPECIMENS
3/32" 25 - - - 38 - SPECIMENS

HEAT TREATMENT AFTER WELDING FOR 61 S SPECIMENS – SOLUTION TREATED AT 970°F – WATER QUENCHED – AGED 8 HOURS AT 350°F

include actual welding speeds at which these fillets were made in the flat, horizontal, vertical and overhead positions. The heat treatment of the 61S-T6 plate specimens increased the shear strengths of the welds considerably, indicating considerable alloying with the plate. All of the specimens failed by shearing through the throat of the welds. The shear strength values were calculated on the measured fractured areas of the welds below the root of the fillet. A macrosection of the double-tee joint in 1-in. 38F plate is shown in Fig. 14. The penetration in this weld extends considerably below the root of the fillet. The shear strength obtained in this weld made with 2S wire is proportionately greater than the strengths of the smaller specimens welded with 43S wire, based on the respective tensile strengths of these materials. This is not the effect of penetration but of better alignment of the specimens made of the heavier plate material. The weld fractures were all acceptably sound and comparable to typical fractures of structural steel welds made with coated electrodes.

The mechanical properties of butt joints made in the flat position with this process are shown in Table IV in which the welding procedure used for these joints is also presented. These are representative joints in which full advantage of the deep penetration of the process is taken for maximum welding speeds and to obtain a heat-treatable weld metal with 43S wire. Another example of the capability of the process for welding in deep narrow grooves is shown in Fig. 15. Macrosections of the welds in 1-in. 3S plate and the weld in 3/8-in. 61S-T6 plate in the table are shown in Figs. 16 and 17. The speeds at which these joints were welded are very high when compared to other manual processes. The tensile strengths of these welds are comparable to the strengths of the plate. Heat treated welds in 61S-T6 plate developed practically the full strength of the unwelded heat-treated plate material. The

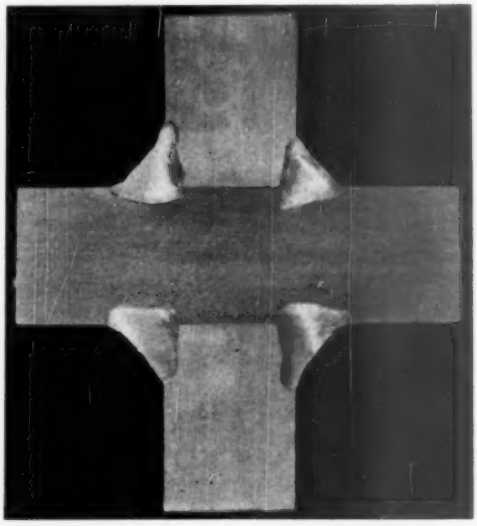

Fig. 14 Weld section of the 1-in. fillet weld shear test specimen

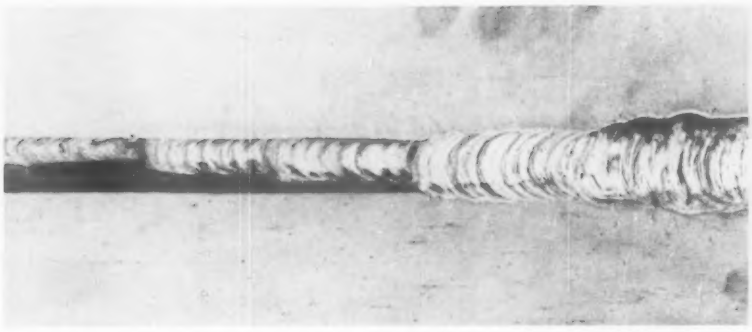

Fig. 15 Manual multipass weld in a narrow groove joint in 1-in. aluminum

TABLE- IV

PROCEDURES AND MECHANICAL PROPERTIES OF ALUMINUM BUTT WELDS MADE WITH AIRCOMATIC GUN

PLATE MATERIAL	JOINT & BEAD SKETCH	WIRE DIA	GAS FLOW CFH	PASS	CURRENT AMPS	ARC VOLTAGE	*SPEED OF JOINT IN / MIN	TENSILE STRENGTH PSI	TENSILE FRACTURE
$\frac{3}{16}$" 3S-F		$\frac{1}{16}$" 2S	ARGON 30	1	190	19	26	14 875	PLATE
$\frac{3}{8}$" 2S-F		$\frac{1}{16}$" 2S	HELIUM 50	1-2	255	30	11	13 100 13 100	PLATE
1" 3S-F	90°	$\frac{3}{32}$" 2S	HELIUM 75	1 2 3-4	315 335 305	35 34 34	3.7	18 125 18 250	WELD WELD
$\frac{3}{8}$" 61S-T6		$\frac{1}{16}$" 43 S	HELIUM 50	1-2	245	30	12	28 600 29 300 43 800* 44 500*	PLATE
$\frac{1}{2}$" 61S-T6	30°	$\frac{3}{32}$" 43 S	HELIUM 75	1 2	325 330	31 31	4.3	25 200 25 900 42 000* 38 400*	PLATE PLATE WELD WELD

* SPEEDS ARE COMPOSITE FOR ALL BEADS AT 100 % ARC TIME - ALL WELDS WERE MADE WITHOUT CHIPPING ROOTS - WELD REINFORCEMENT REMOVED ON TENSILE SPECIMENS.

* HEAT TREATMENT - SOLUTION TREATED AT 970°F - WATER QUENCHED - AGED 8 HOURS AT 350° F.

ductility of 2S welds made in 2S and 3S plate is sufficient to permit the use of the standard guided bend test. A side bend-test specimen of a 1-in. 3S weld is shown in Fig. 18. The ductility of welds in 61S-T6 plate welded with 43S wire is too low to make the standard welded joint bend tests applicable. Radiographs of these butt welds are acceptable under existing pressure vessel standards.

Automatic Welding

The field of application of the Aircomatic head for welding aluminum alloys is similar to that of other automatic processes and is principally for quantity production jobs involving heavy plate fabrication in the flat position where high welding rates are advantageous. The current range for welding aluminum with the head is from 300 to 650 amp. The head can be used for welding butt joints in material $\frac{3}{8}$ in. and greater in thickness. Horizontal fillets can be made in heavy material with difficulty and it is usually more practical to use the manual gun for this purpose.

The head uses bare wire in coil form $\frac{3}{32}$ to $\frac{3}{16}$ in. in diameter. The most practical size is $\frac{1}{8}$ in. and this size can be used over with full current range of the head. Metal transfer in the low current range tends to be globular. This type of transfer is practical for flat welding with the head since this equipment controls the rate of feed by arc voltage.

Welding rates and production costs can be calculated from the deposition chart shown in Fig. 19. Helium is preferred to argon for practically all automatic welding. The arc heat is higher for a given current and arc length,

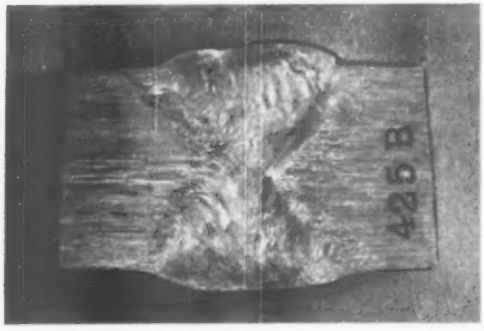

Fig. 16 Macrosection of a manual 4-pass weld in 1-in. thick 3S aluminum plate

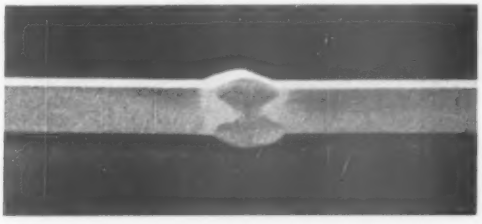

Fig. 17 Macrosection of a manual square-butt joint in $\frac{3}{8}$-in. thick, 61S aluminum plate

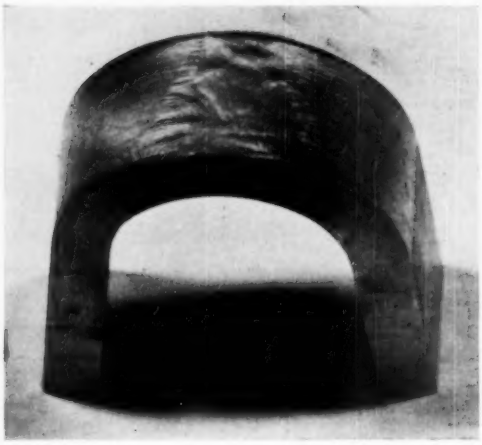

Fig. 18 Side-bend test of a manual 1-in. aluminum butt joint

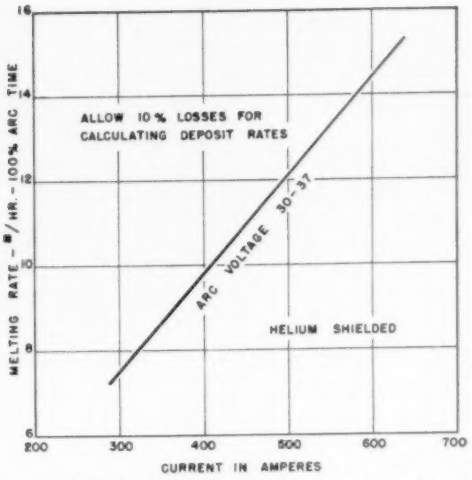

Fig. 19 Average welding rates $^1/_8$-in. diameter aluminum wire

penetration is deeper, and the edge of the weld wet in smoothly with the plate. With argon shielding the weld beads tend to be convex and the edges do not wet in smoothly. Higher welding currents can be used with helium, and for a given job the maximum welding speed is appreciably faster with helium than with argon.

The welding procedure used for a few typical joints made with the head are tabulated in Table V. The joint designs are such as to take full advantage of the deep penetration characteristics of the process. No root chipping of these joints is required. The welding grooves are designed to permit the required penetration and provide a space for the deposited metal so that it does not pile up as excess reinforcement. It is usually preferable to weld the joints from both sides, but completely fused welds can be made from one side providing suitable backing is used. It is quite often advantageous to weld one side of a joint in heavy plate with the gun, providing not more than $^1/_4$-in. penetration is required.

Fully automatic control of the process with the head makes the production of sound welds a relatively simple matter. The high rate of heat input to the welds which is associated with the high current and slower travel speed used results in a large molten weld puddle which solidifies relatively slowly thereby giving any gas in the weld sufficient chance to escape. The vigorous arc action of high welding currents replaces the oscillation technique usually required with the gun for producing sound welds so that a straight steady forward travel of the electrode can be used. All the welds shown were radiographed and found acceptable according to existing pressure vessels standards. A group of test specimens in heavy 38 plate are shown in Fig. 20 (*A*). A side bend-test specimen of the $1^1/_2$-in. butt joint in Table V is shown in Fig. 20 (*B*). These specimens are typical of the automatic process. The mechanical properties of automatic welds are given in Table VI. The effect of alloying 43S weld metal with 61S plate is shown by the increased strength of this material in a joint, compared to its all-weld metal strength. Heat treatment further increases the strength of alloyed 43S weld metal as is the case for welds

TABLE – V

WELD PROCEDURES FOR ALUMINUM WITH THE AIRCOMATIC HEAD

PLATE	JOINT & BEAD SKETCH	WIRE DIA.	HELIUM FLOW CFH	PASS	CURRENT AMPS	ARC VOLTS	JOINT SPEED IN/MIN.
$^1/_2$"	40° COPPER	$^1/_8$"	75	1	420	30	18
$^3/_4$"	90°	$^1/_8$"	75	1-2	385	30	8
1"	90° COPPER	$^1/_{16}$"	120	1	650	34	9
$1^1/_2$"	90°	$^1/_8$"	100	1-2	570	35	4

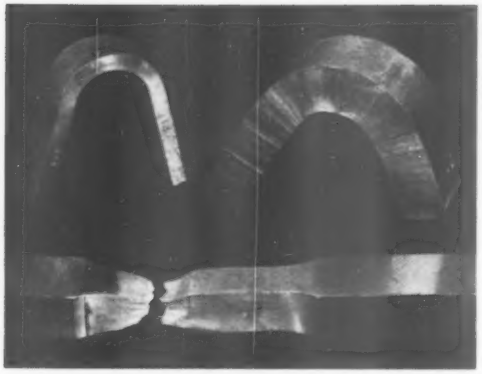

Fig. 20 (A) Photograph of a group of weld test specimens in heavy aluminum plate made with the aircomatic head

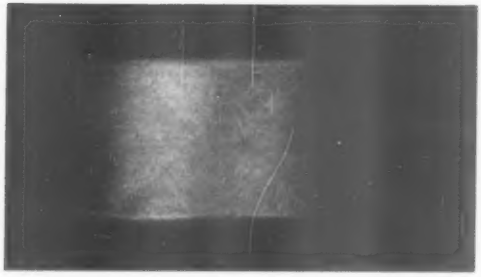

Fig. 20 (B) Side-bend test specimens of a 1½-in. 2-pass aluminum butt joint made with the aircomatic head

made with the manual method. The tensile strengths and ductility of weld specimens tested at −320° F. show the excellent performance of welded-aluminum joints at these low temperatures.

A series of impact specimens were made from a butt joint in 1-in. 3S plate made with 2S wire. Standard V-notched Charpy specimens were tested with the notch cut in the weld metal transverse to the axis of the weld and parallel to the plate surface. The results of these tests are shown in Table VII.

Table VII—V-Notched Charpy Impact Strength of 2S Aluminum Weld Metal

Testing temp., ° F.	*Impact strength, ft.-lb.*	
	Specimens from top of weld	*Specimens from bottom of weld*
66	22	38
	26	39
	25	33
−6	28	38
	33	40
	31	36
−100	29	36
	33	32
	34	36
−320	24	21
	23	22
	20	22

STAINLESS STEELS

All of the commercial austenitic type stainless steels can be successfully welded with the Aircomatic process. Welding with the manual gun may be performed in all positions. Preheat is not required for welding. It is necessary to use controlled filler wire compositions to avoid the cracking difficulties commonly encountered in welding stainless steel. The precautions which must be observed are similar in many respects to those used in balancing core wire compositions for coated electrodes, except allowances do not have to be made for loss of elements in transfer. At present ⅛ in. and heavier plate can be welded. The lower limit of thicknesses is occasioned by the present status of available apparatus and it is expected that when suitable equipment is available for welding thin materials no difficulties will be encountered.

One-eighth inch thick and heavier plate can be rapidly welded in the flat position using 0.062-in. diameter wire. All position welding can be accomplished using 0.035- and 0.045-in. diameter wire. The wide range of current and arc voltage that may be used with each filler wire size permits excellent control of penetration and deposition rate during welding. It is possible to weld 3/16-in. plate in one pass with complete penetration using 0.062-in. diameter electrode wire. With the same wire a ½-in. square butt joint can be welded in two passes, one from each side, without back-chipping or grinding. A typical cross section for such a weld is shown in Fig. 21. The current and wire feed rate may also be reduced where overheating must be avoided so that five or more passes

TABLE – VI

MECHANICAL PROPERTIES OF ALUMINUM WELDS MADE WITH THE AIRCOMATIC HEAD

TEST SPECIMEN	WIRE	PLATE	TENSILE STRENGTH PSI	REDUCTION IN AREA %	ELONGATION %	REMARKS
ALL WELD METAL (505)	2S	1" 3S	17 900	3.6	25	
	43S		22 400	8.6	8.4	
REDUCED SECTION TENSILE	2S	¾" 2S	13 100			
		1" 3S F	16 030			FRACTURE IN PLATE
	43S	¾" 61 S T 6	27 500			
			45 350	HEAT TREATED		
		1½" 3S F	18 870			FRACTURE IN WELD
			27 700	AT −320 °F		
FREE BEND TEST	2S	1" 3S F			44	180° BEND ANGLE
					32	130°
		1½" 3S F			30	
			AT −320° F		28	
GUIDED SIDE BEND TEST		¾" 2S				180° NO DEFECTS
		1" 3S F				
		1½" 3S F				
			AT −320° F			

Table VIII—Welding Procedure for Austenitic Stainless Steels

Plate thickness, in.	*Welding position*	*Wire size, in.*	*Shielding gas*		*Current range, amp.*	*Wire feed range, in./min.*	*Deposition rate lb./arc hr.*
			Kind	*Flow, cfh.*			
1/8–1/4	All	0.035	He	20–30	110–150	220–310	3.7–5.2
1/4–1	V & O	0.035	A	20–30	110–140	220–260	3.7–4.3
1/2–1	V & O	0.045	A	20–30	140–180	150–200	4.1–5.3
3/16–3/8	F & H	0.045	A	30–40	190–310	210–440	5.7–11.8
1/4 and up	F & H	0.062	A	30–40	280–350	240–330	12.6–17.3

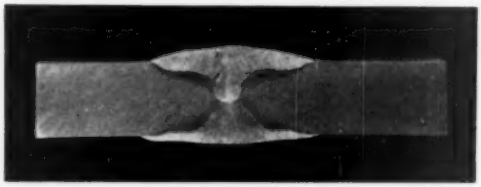

Fig. 21 Macrosection of a square butt joint in 1/2-in. thick stainless steel made with 1/16-in. electrode wire

are required to weld a 1/2-in. beveled butt joint. Where minimum dilution is important, current and arc voltage may be controlled so that the deposited metal may be deposited with little penetration. In general a low-current long-arc tends to deposit metal with little penetration whereas a high-current short-arc penetrates deeply. Ability to operate a given electrode filler wire at a variety of current and voltage conditions permits control of penetration to a degree that cannot be approached with conventional coated electrodes.

Typical welding conditions for various thicknesses of stainless steel plate are shown in Table VIII. Both argon and helium are used for shielding gases with argon preferred for welding plates above 1/8 in. thick and helium preferred for the thinner materials. Data are contained in the last column of the table which show the high deposition rates and hence rapid welding speeds which are characteristic of the Aircomatic process. Losses due to spatter and vaporization average less than 1% when welding stainless alloys.

Welding technique is similar to that conventionally used in welding stainless steels with coated electrodes. The usual control of heat input must be observed when the "sensitive" or unstabilized alloys are welded. Figure 22 shows a typical butt joint made in the flat position in 1/2-in. thick, Type 316 (18-8 Mo) plate using Type 316 wire. This weld was made in the flat position using 0.062-in. diameter wire fed at 240 in. per minute, a current of 380 amp., arc voltage of 34 v., and travel speed of 11 in. per minute. The electrode wire feed rate used corresponds to a deposition rate of 12.6 lb. per hour

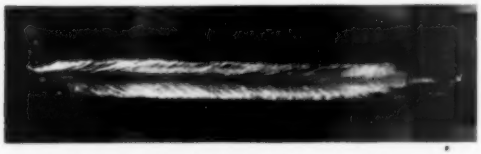

Fig. 22 Photograph of a typical butt joint in stainless steel made in the flat position

which further illustrates the high welding speed which can be attained with this process. Figure 23 shows a typical multipass fillet weld made in 1/2-in. Type 321 (18-8Ti) plate welded in the vertical-up position. This weld was made using 0.035-in. diameter Type 321 wire, fed at 250 in. per minute, current of 115 amp., arc voltage of 21 v., and travel speed of 4 in. per minute. Sound

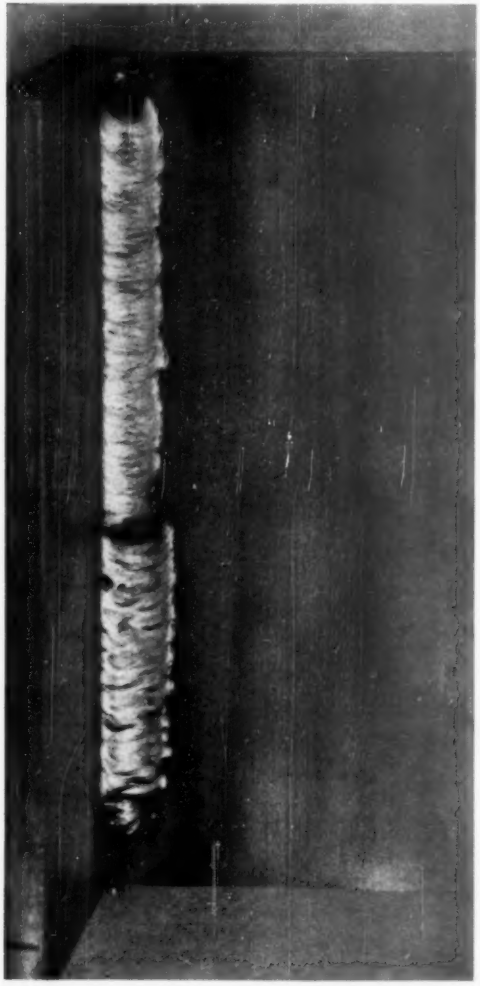

Fig. 23 Photograph of a multipass fillet weld in stainless steel made in the "vertical-up" position

Table IX—Chemical Composition of Austenitic Stainless Steel Filler Wire and of Resulting Weld Deposit

AISI type	*Sample*	*C*	*Mn*	*Si*	*Ni*	*Cr*	*Mo*	*Ti*	*Cb*
347	Wire	0.068	1.17	0.41	10.48	19.64	...	...	1.39
347	Weld	0.059	1.15	0.40	10.53	19.58	...	...	1.29
302-B	Wire	0.091	1.41	2.54	8.74	17.69	...	...	...
302-B	Weld	0.120	1.41	2.35	8.83	17.91	...	...	...
308 Ti	Wire	0.075	1.24	0.69	9.44	18.13	0.18	0.17	...
308 Ti	Weld	0.080	1.18	0.74	9.40	18.37	0.18	0.11	...

Fig. 24 Photograph of a "vertical-down" fillet weld in 1/4-in. stainless steel

metal of excellent quality can be deposited using these conditions. Figure 24 shows a typical vertical-down single-pass fillet weld made in 1/4-in. plate using a current of 152 amp., arc voltage of 30 v., travel speed of 37 in. per minute, electrode feed of 350 in. per minute with helium for shielding. Particular attention is directed to the fact that vertical-down welding can be performed with good penetration as shown in 1/4-in. thick plate in Fig. 25. This type of welding generally cannot be satisfactorily accomplished with coated electrodes except in very thin sheet.

The chemical composition of the filler wires used for welding austenitic stainless steels with this process are nominally the same as the base plate to be fabricated except that the wire analysis must be maintained within

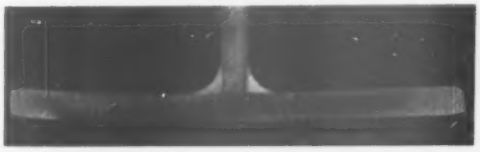

Fig. 25 Macro-section of a "vertical-down" fillet in 1/4-in. thick stainless steel showing complete penetration

narrower limits to prevent cracking of the weld deposits during cooling. This limitation is well known to fabricators and manufacturers of coated stainless electrodes. Balancing the Cr-Ni ratio to insure the presence of delta ferrite in the deposited weld metal eliminates cracking in the 18% Cr–8% Ni type alloys. Proper adjustment of the carbon, silicon and phosphorus content prevents cracking when depositing the 25% Cr–20% Ni alloy.

With this inert-gas-shielded metal-arc process all of the elements present in the electrode wire are transferred with practically 100% recovery except titanium. Titanium can be transferred across the arc and recovered to the extent of about 60% in the weld deposit. This high efficiency for titanium transfer cannot be obtained with coated electrodes. The ability to transfer titanium in large quantities permits the use of titanium stabilized wire for welding, a fact which may be of considerable importance should a columbium shortage develop. Table IX illustrates the high-transfer efficiency for various chemical elements. Except for reduced titanium, weld deposits made with this process have the same chemical analysis as the wire used for welding. This ability to deposit a carefully controlled predetermined chemical analysis of weld metal is believed to be of considerable importance in applications where critical corrosion or high-temperature expansion problems are encountered.

Stainless steel welds made with this process possess excellent properties. Table X shows the mechanical properties of all weld-metal test specimens made in Type 304 (18–8) plate using Type 304 electrode wire. Tensile and yield strengths of the as-welded metal are higher than those of the annealed weld metal. Ductili-

Table X—Mechanical Properties of All Weld Metal Type 304 Deposits

	As-welded	*Annealed**
Tensile strength, 10^3 psi.	86.0–90.2	80.0–78.4
Yield strength (0.2% offset), 10^3 psi.	52.5–57.0	38.2–37.3
Elongation, per cent in 2 inches	47.0–59.4	52.4–54.0
Reduction of area, %	57.3–65.2	62.5–62.5
Rockwell B hardness	87.0–83.0	78.6–80.0

* Heated to 2000° F., water quenched.

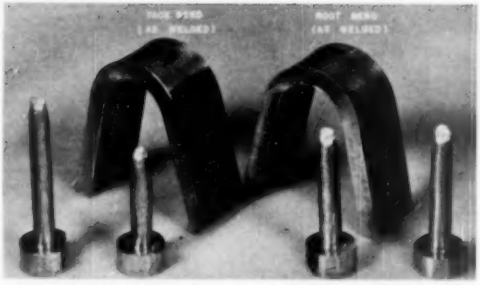

Fig. 26 Photographic of stainless steel all-weld metal tensile and guided-bend test specimens

ties are high for both as-welded and annealed specimens as shown by the elongation and reduction in area figures. Photographs of the as-welded and annealed tensile bars after testing are shown in Fig. 26. The results of testing typical transverse test specimens and face and root-bend test bars are also shown in this figure. These specimens were prepared using $^3/_8$-in. type 347 plate (18-8 Cb) and Type 304 wire. The average transverse tensile strength of duplicate test bars was 85,000 psi. The tests were made with reinforcement removed. Failure occurred in the weld metal. Face and root-bend specimens withstood a 180° bend.

In order to determine the toughness of stainless-steel weld deposits at room and subzero temperatures, transverse V-notched Charpy test specimens were tested at several temperatures. The notch was located at the center of the weld metal with its axis perpendicular to the plate surface. The impact strengths at temperatures ranging from 67° to −320° F. are shown in Table XI and presented graphically in Fig. 27. The V-notched Charpy impact strengths of Type 304 weld metal ranged from 107 ft.-lb. at room temperature to 36 ft.-lb. at the temperature of liquid nitrogen. No evidence of transition to brittle behavior occurred in this range of temperature. In general, the mechanical properties of stainless-steel welds made with the Aircomatic process are equal or slightly superior to those obtained with conventional coated electrodes.

Table XI—Impact Strength of Type 304 Weld Metal

Test temperature, ° F.	*Impact strength, ft.-lb.*
67	112
67	102.5
	Av. 107.2
−40	72
−40	73
−40	65.5
	Av. 70.2
−100	66
−100	59
	Av. 62.5
−320	33.5
−320	41
−320	33.5
	Av. 36.0

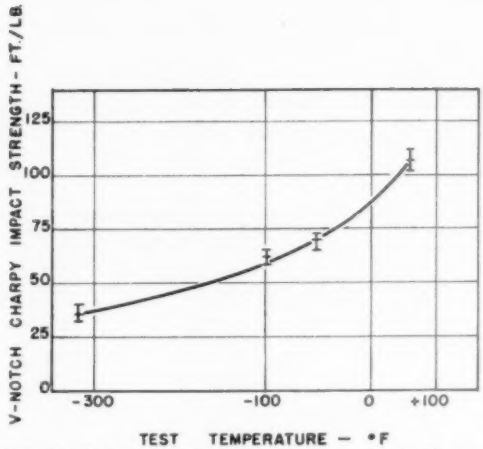

Fig. 27 Influence of temperature on v-notch Charpy impact strength of Type 304 weld metal

The microstructure of as-deposited Type 304 alloy comprises delta ferrite and traces of carbide in an aus-

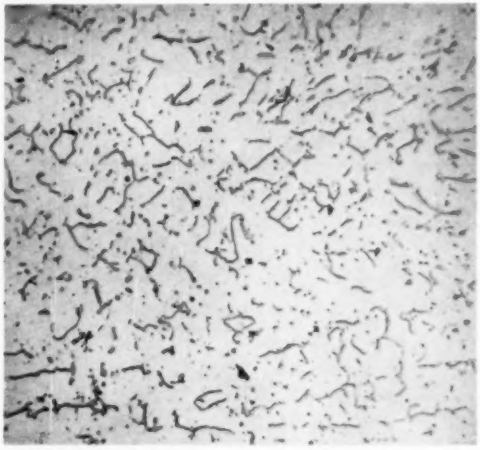

Fig. 28 Microstructure of as-deposited, Type 304 weld metal showing delta ferrite and trace of carbide in the austenitic matrix. × 500

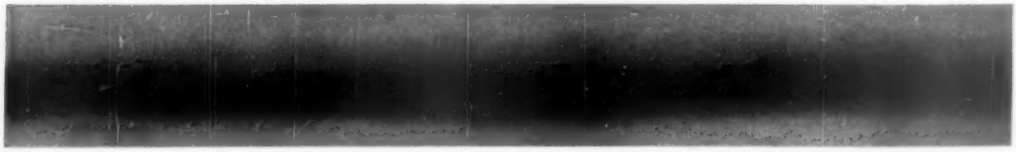

Fig. 29 Radiograph of a typical weld in Type 347 stainless welded with Type 347 electrode wire

tenitic matrix as shown in Fig. 28. The weld metal is relatively free from inclusions and is sound. Porosity is not a serious problem in welding austenitic stainless steels. Hydrogen is soluble to a considerable degree in solid austenitic stainless steel, therefore, no trouble is experienced from this element such as is encountered in welding aluminum. Poor welding technique involving rough arcs and improper shielding may lead to porosity. A radiograph showing a typical weld made using Type 347 plate and 347 wire is shown in Fig. 29. Practically no porosity is evident and no difficulty is encountered in making similar quality welds in the vertical-up, vertical-down and overhead positions. With proper arc conditions and suitable filler wire a trained operator can produce welds which satisfactorily comply with all of the requirements of existing codes for pressure vessel welding.

Heat Resisting Alloys

Some work has been done which involves the welding of high-temperature alloys. Figure 30 (*A*) shows a macrosection of a weld made in 1-in. S-590 heat-resisting alloy using 0.078-in. diameter S-590 wire. The nominal chemical composition of this material is 0.50% C, 0.6% Mn, 0.2% Si, 20% Cr, 20% Ni, 20% Co, 4% Mo, 4% W and 4% Cb. This joint was made without using the customary high preheat employed for welding materials of this type. The joint design used is shown

Fig. 30 (A) Macrograph of a weld in 1 in. thick S-590 heat-resisting alloy using S-590 electrode wire

in Fig. 30 (*B*) and details of the welding procedure used are shown in Table XII. The ability of this process to deposit a wire analysis exactly the same as that of the material which is being welded greatly minimizes difficulties in fabricating high-temperature alloys. Elimination of regions containing material possessing a different coefficient of expansion and different properties at elevated temperature minimizes design and operating difficulties. The reduced preheat requirements for making joints under conditions of severe restraint greatly simplifies welding. Although much remains to be done in the field of welding heat-resisting alloys it appears that the inert-gas-shielded metal-arc process offers many advantages for fabricating these materials.

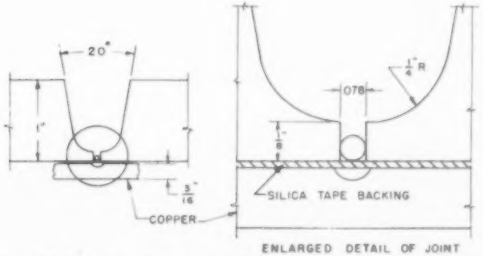

Fig. 30 (B) Details of the joint design of the above 1-in. butt weld in S-590 alloy

Table XII—Welding Procedure for 1-In. S-590 Plate

Shielding gas	Argon–60 CFH
Wire diameter, in.	0.078
No. of passes	5
Arc current, amp.	340–360
Arc voltage	23–26
Travel speed	10–15
Electrode feed rate	218–235
Preheat*	None

* Maximum interpass temp., 350° F.

Clad Materials

A square butt joint made in 3/8-in. thick 20% nickel-clad steel plate is shown in Fig. 31. This weld was made using 0.062-in. diameter nickel wire at a current of 350 amp. for the steel side, 300 amp. for the nickel side, arc voltage of 31 v. and a travel speed of 15 in. per minute. The steel side was welded first. No preheat was required for welding. No cracking occurred in any of the deposits. It is possible to control dilution in joints of this type so that iron pickup in the weld bead on the clad side can be readily maintained under 10%. Where corrosion is a problem this control is important. Figure 32 illustrates the control of penetration which may be exercised in welding of this kind. Three beads were deposited on 10% nickel-clad steel with nickel wire using welding conditions designed to produce deep penetration, medium penetration and minimum penetration. This flexibility permits accurate control of dilution in applications where this factor is critical.

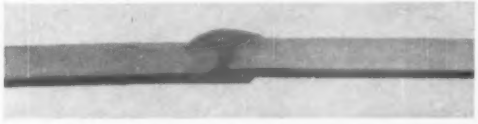

Fig. 31 Macrosection of a square butt joint in 3/8-in. thick nickel clad steel

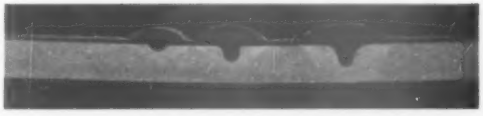

Fig. 32 Bead welds on nickel clad steel showing the degree of control of penetration and dilution with the aircomatic process

ALUMINUM BRONZE

The welding of aluminum bronze has been investigated using the Aircomatic process. Welding proved

to be surprisingly simple and some excellent results have been obtained. The equipment required is essentially the same as that necessary for welding aluminum. Two aluminum-bronze welding wire analyses have been used successfully for overlay and joining purposes. One analysis, an α-β type composition, contains about 10% aluminum, 1% iron and the balance copper; the other is an α bronze containing 8% aluminum without iron. Welded joints have been made in aluminum bronze, carbon steel and propeller-type bronze. Various metals have been surfaced with welded overlays suitable for bearing purposes including mild steel, gray cast iron, deoxidized copper, naval brass and manganese-bronze marine propeller casting alloy. No attempt has yet been made to deposit hard abrasion resistant overlays of higher aluminum content.

The metallurgy of aluminum-bronze welds is quite complex, particularly when welding dissimilar metals. Chemical analyses of wire and deposited metal show that no aluminum is lost during deposition but that alloying with the base metal may be considerable, particularly in the first pass. The amount of alloying can be controlled by the welding technique and usually can be limited to the first layer of an overlay. The presence of iron in aluminum bronze acts as a grain refiner and tends to harden and strengthen the metal. On all of the metals surfaced with aluminum bronze, a sound tightly adherent bond was obtained and no cracking was observed. The microstructure of an aluminum bronze overlay on mild steel is shown in Fig. 33. The overlay portion consists of an α solid solution matrix containing dark etching eutectoid. The zone between the first and second layers of this deposit is shown in Fig. 34 and contains less eutectoid.

The bond zone in cast iron is sharp, but the overlay contains globules of cast iron. The microstructure of the bond zone of an overlay on copper is shown in Fig. 35. This photomicrograph shows some grain boundary continuity across the interface. The interface of an overlay on bronze propeller alloy shows diffusion of zinc into the aluminum bronze. All of these overlays were sound on radiographic examination.

When aluminum bronze wire is deposited with this process the arc characteristics are very good. Argon is preferred to helium for shielding because the arc is smoother and there is practically no spatter. Weld

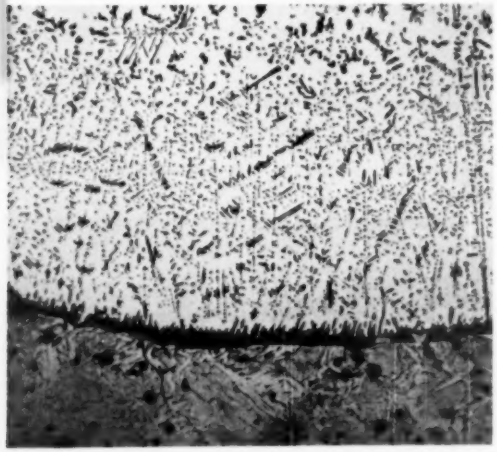

Fig. 33 Microstructure of the bond zone of an aluminum bronze overlay on mild steel plate. × 250

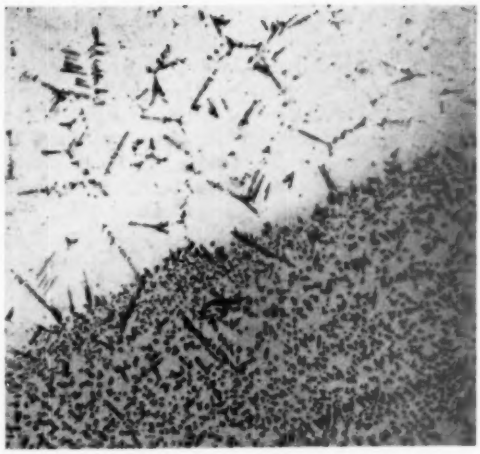

Fig. 34 Microstructure between the first and second layers of aluminum bronze on the same specimen as Fig. 33. × 250

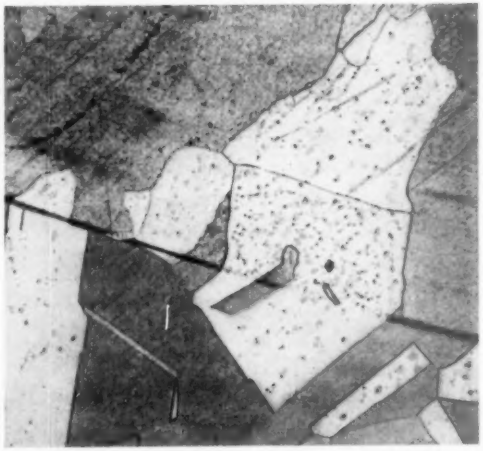

Fig. 35 Microstructure of the bond zone of an aluminum-bronze overlay on a copper plate. × 250

Fig. 36 Photomacrograph of vertical and horizontal fillet welds in $\frac{1}{2}$-in. aluminum-bronze plate

Fig. 37 Macrosection of a 3-layer overlay of aluminum bronze on a $^3/_4$-in. steel plate

beads are produced which have a smooth surface and a bright gold color. At 200 amp. and above the arc has a smooth spray-like projected metal transfer with 0.062-in. diameter wire. Welds can readily be made in the vertical position with 0.035-in. diameter wire. Figure 36 shows fillet weld cross sections made in aluminum-bronze plate in the horizontal and vertical positions. Sound weld deposits in the flat position can be made over a wide current range, the arc length and manipulation are not critical. Base metal alloying can be kept at a minimum by welding with a "backhand" technique whereby the gun is pointed back from the direction of travel so that the arc impinges on previously deposited metal and the added metal runs ahead under the arc. The uniformity of the fusion zone can be seen on the macrosection of a 3-layer overlay deposit on a $^3/_4$-in. steel plate shown in Fig. 37. The smoothness of the deposited beads and the soundness of the deposit are shown in the photograph of this deposit in Fig. 38.

The rate of depositing aluminum-bronze weld metal is high. Burn-off and deposition rates for 0.062-in. wire are shown in Table XIII. Aluminum bronze in larger wire diameters can be deposited with the Aircomatic head. Excess dilution of the base metal limits the currents that can be used for the first layer. Using the automatic head at a current of 380 amp. with $^1/_8$-in. wire deposits can be made with minimum dilution, holding a square built-up edge.

Table XIII—Burn-Off and Deposition Rates for 0.062-In. Aluminum-Bronze Wire

Current, amp.	*Argon flow, cfh.*	*Burn-Off, in./min.*	*Deposition rate, lb./arc hr.*
175	30–40	140	7.5
250	30–40	210	12.0
325	30–40	325	17.5

Table XIV—All-Weld Metal Properties of Aluminum-Bronze Deposit on $^3/_4$-In. Mild Steel Plate

	Analysis, %			*Hardness*	*Ultimate tensile strength, psi.*	*Elongation, %*
	Cu	*Al*	*Fe*			
Wire	89.3	9.9	0.73	...	...	...
All-weld metal deposit	84.9	9.3	5.7	R_B 91	110,000	20
Wire	90.5	9.2	0.15	...	...	...
All-weld metal deposit	89.6	8.8	1.55	R_B 70	70,750	28.5

The mechanical properties of aluminum bronze welds are excellent. All-weld metal tests for two types of aluminum bronze deposits made on steel are shown in Table XIV. The first specimen was welded with a technique that produced considerable plate metal dilution. The second specimen was made with a different wire analysis and welded with a technique to minimize plate metal dilution. The differences in aluminum and iron content of the resulting deposits is reflected in their respective mechanical properties. It is interesting to note that the increased alloy content has caused the strength to increase at a higher rate than the ductility decreased.

A 60° V-grooved butt joint with backing was braze welded from one side in mild steel plate with aluminum-bronze wire. Standard reduced section tensile tests and guided-bend test specimens were prepared from the test joint. Because the bronze is stronger than the steel the tensile specimens broke outside the weld in the plate material at an average strength of 66,000 psi. Both face and root-bend specimens bent 180° without cracking. A photograph of these test specimens is shown in Fig. 39. These tests demonstrate the effectiveness of the bond between the bronze and steel. No mechanical tests other than hardness were made of the overlay specimens of copper, cast iron or bronze propeller alloy, but visual microexamination showed no cracking.

The welding of copper alloys containing zinc presents

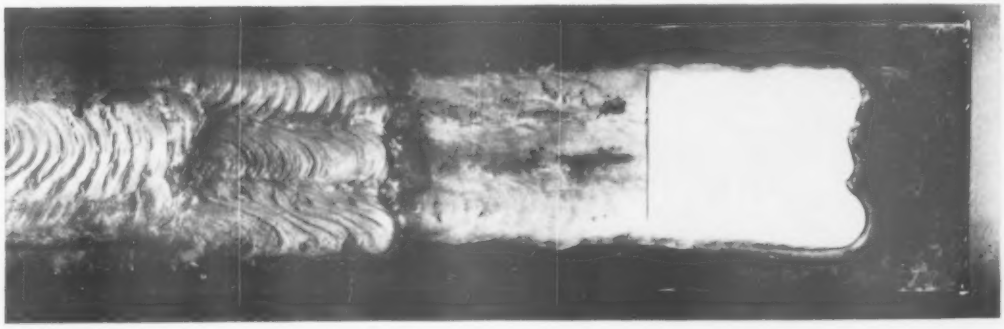

Fig. 38 Photograph of the overlay on steel showing the smoothness of the beads and the soundness of the metal on the machined surface

a special problem. If the arc impinges directly on the base metal, some of the zinc is vaporized which disturbs the arc making it rough and causing an excessive amount of spatter. However, if the current for the first layer of a deposit is kept low (about 170 amp.) and the back-hand welding procedure described for minimum dilution is followed, a satisfactory layer can be applied. After the first layer the current may be increased to any practical value and the welding will proceed smoothly as with other materials. An overlay deposit of aluminum bronze on a section of a heavy cast manganese-bronze propeller blade is shown in Fig. 40.

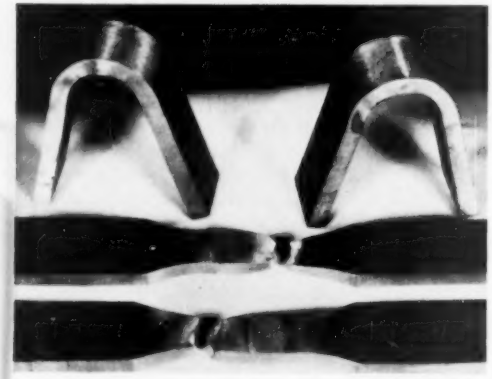

Fig. 39 Photograph of bronze-welded steel guided-bend and tensile test specimens

A macrosection of a butt weld made in this material using aluminum-bronze electrode is shown in Fig. 41. No preheat or flux is necessary for this type of welding which is extremely difficult to perform by any other known welding method.

Part II—Applications

INTRODUCTION

Since the announcement of the Aircomatic process a year ago[10] considerable experience in its practical application has been obtained. It was apparent that the process would find application in those fields where heavy sections of aluminum were welded, but just how it would find acceptance and on just what sort of welded fabrication it would be used was a matter of speculation.

Although there has been only a year for gas-shielded metal-arc welding to find its place relative to existing welding methods, it is already established in a number of fields principally on two broad counts:

1. Greatly increased speed of welding resulting in lower over-all costs of welding.
2. Reduced distortion and a clean weld resulting in lower costs after welding.

The typical applications to be described illustrate these points and show how this new process claims its place in harmony with other methods, taking over jobs for which they are not entirely suitable.

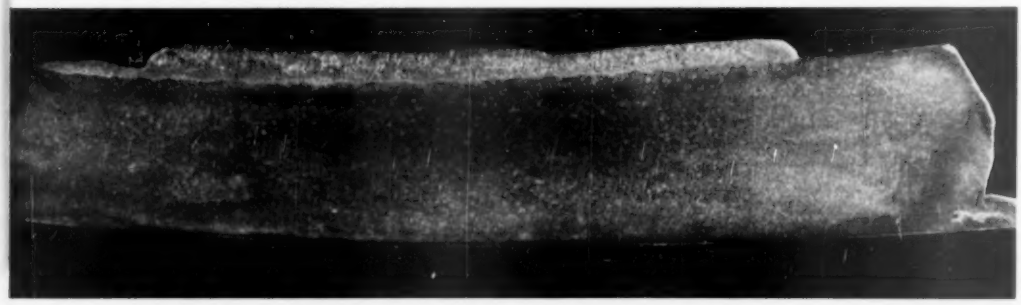

Fig. 40 Macrosection of an aluminum-bronze overlay on manganese bronze. (Actual size)

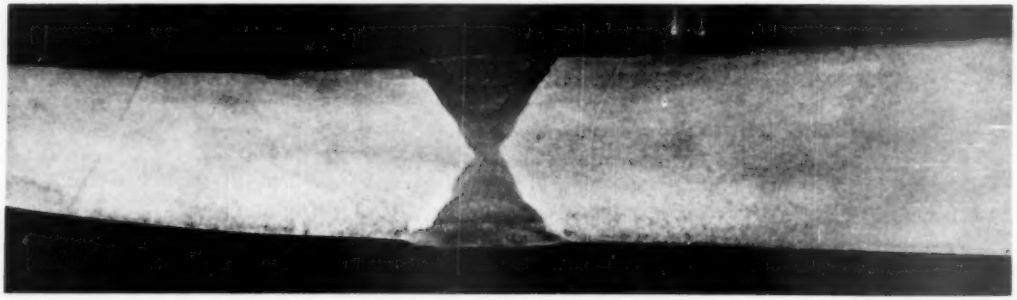

Fig. 41 Macrosection of a butt joint in section of a manganese-bronze propeller welded with aluminum-bronze wire. (Actual size)

EQUIPMENT AND TECHNIQUE OF WELDING

To some extent the apparatus and its method of use have previously been described in the technical press[10–12] a detailed description is not warranted here. The gun of the equipment shown in Fig. 1 of Part I of this paper is better depicted in Fig. 42. When the operator is ready to weld, he squeezes the trigger, thus closing control circuits that start the flow of shielding gas and apply open-circuit welding voltage to the protruding filler metal wire. This latter is scratched on the

Fig. 42 The manual gun showing the wire electrode protruding from the gas nozzle

work initiating the arc. With the establishment of arc voltage wire feed begins and continues as long as the arc voltage exists, unless the operator releases the trigger. The instant that wire feed begins the operator manipulates the gun to place the filler metal where desired as in Fig. 43 where the second pass of a vertical butt weld is being made in the bottom course of the tank shown under construction in Fig. 44.

Fig. 44 Aluminum formaldehyde storage tanks 40 x 35 ft. under construction. Welding unit is inside

SIMPLE STRUCTURAL APPLICATIONS

On this outdoor application much experience was gained. The aluminum tank pictured in Fig. 44 is now 40 ft. high x 35 ft. in diameter. The lower courses are of 1 in. 28 material. If the problem of outdoor work had been solved sooner, all of this tank would have been welded by the gas-shielded metallic-arc process, but instead the contractor had to use tungsten arc and gas welding in order to complete the job on time. One of the things learned was that the operation must have some sort of crude windbreak to preserve the proper coverage of shielding gas as in Fig. 45 where the opera-

Fig. 43 Making a two-pass weld vertically upward on 1-in. thick 28 aluminum

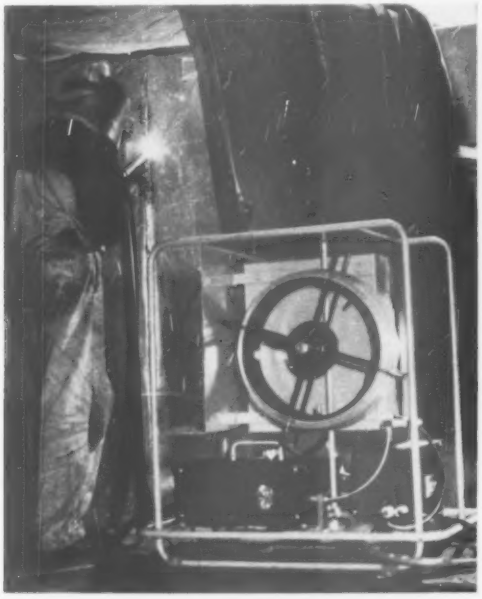

Fig. 45 A tarpaulin is used to break the force of the wind on outdoor work

Fig. 46 Unassembled and completed brackets of 61S welded on both ends

tor is welding a vertical butt prepared using a double 90° Vee with $^{3}/_{32}$-in. root face. A tarpaulin on a wooden frame breaks the force of the wind. The $^{1}/_{16}$-in. 2S filler wire is fed at about 200 in. per minute using a welding current of 190 amp. This gives a high deposition rate of 3.7 lb. per arc hour. Here argon (33 cu. ft./hr.) was used as the shielding gas, although in the light of present knowledge, the recommendation now would be to use helium. Reversed polarity direct current is used for all aluminum work.

A very simple fabrication (Fig. 46) of aluminum brackets illustrates some of the economies possible with

Fig. 47 Twenty four inches of $^{1}/_{4}$-in. fillet welding requires two minutes on these brackets

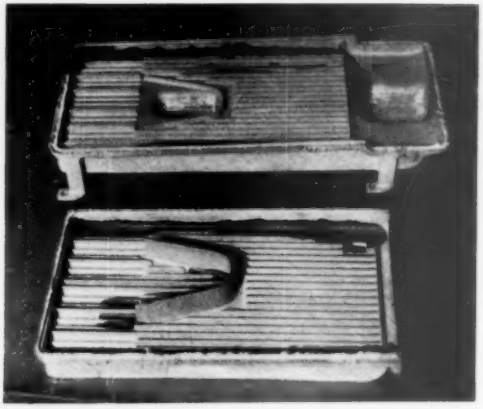

Fig. 48 Halves of aluminum space heater element prior to assembly. Material is cast-aluminum alloy

this new welding process. The top and bottom plates are assembled in a jig with the structural tee and tacked. All members are $^{1}/_{4}$ in. thick, and a $^{5}/_{16}$-in. fillet is run into the joints using $^{1}/_{16}$-in. 2S filler wire. The use of helium (33 cu. ft./hr.) on this job permits of fast welding with 218 amp. of current and 210 in. per minute of wire feed. By placing first one end and then the other on a rotating jig while welding (Fig. 47) the 24 lineal inches of weld are made in only 2 min.

The two halves of a cast aluminum space heater are shown in Fig. 48 prior to being put together and welded by the inert-gas-shielded metal-arc process at a rate of 12 per hour. A tight and low cost job is the result (Fig. 50). Using the tungsten arc-method production is between 6 and 7 units per hour.

Fig. 49 Inert-gas-shielded arc welding the aluminum space heater. Filler metal is 43S wire and the shielding gas helium

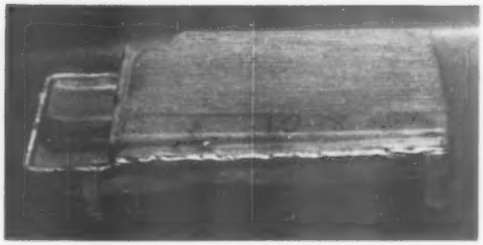

Fig. 50 The completed weld is made in one to two minutes. Production using inert-gas-shielded tungsten arc welding is 6–7 units per hour

Fig. 51 Production line assembly aluminum window sash into frames prior to welding the hinges

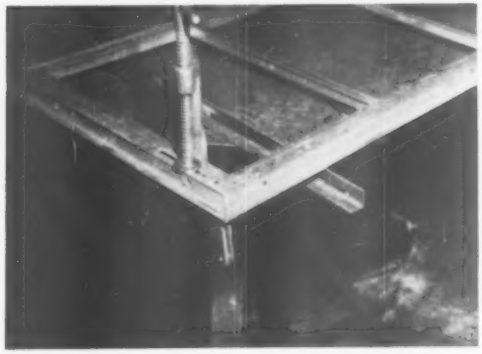

Fig. 52 The $^{3}/_{16}$-in. thick hinge protrudes through the $^{1}/_{8}$-in. thick frame extrusion of 61S-T6 aluminum prior to welding

Fig. 53 Making the weld using $^{1}/_{16}$-in. 43S filler wire fed at 175 in. per minute with 200 amp. of welding current

Probably the metal window casement industry is as highly competitive a one as exists. The product must be strong and serviceable and it is expected to last as long as the building stands, yet there is no survival for a manufacturer who cannot produce a quality product at minimum costs. Where daily production rates are high, a saving of a few cents in an operation is important.

In the production line depicted in Fig. 51, the sash,

Fig. 54 The completed weld takes 5 seconds to make if helium is the shielding gas and 8 seconds if argon is used. Argon requires less cleaning however

window frame and hinges are assembled and clamped so that the assembled sash is ready for welding the hinge. The close-up view, Fig. 52, shows the $^{3}/_{16}$-in. thick hinge ready to be welded to the 61S-T6 aluminum extruded shape in which the metal thickness is about $^{1}/_{8}$ in.

In Fig. 53, the operator is making the weld using 40 cu. ft. per hour of helium as a shielding gas. In this case, $^{1}/_{16}$-in. 43S wire is fed at 175 in. and current is 200 amp. An interesting comparison of the relative merits of helium and argon was made on this job. Using helium as described, the welding on this hinge required five seconds. Using 30 cu. ft. per hour of argon and a slightly higher current (220 amp.) the welding time was increased to eight seconds. The joint made with

Fig. 55 Aluminum air filter assemblies. The tank in the left foreground is inert-gas-shielded arc welded

helium is shown in Fig. 54. Since the tungsten-arc process requires 1 1/2 min. to make this weld, it is scarcely competitive in this instance.

APPLICATION TO MORE INTRICATE STRUCTURES

When welding large structures, it often becomes desirable to use more than one method in order to achieve the lowest over-all costs. In many of the following examples this has been done with considerable degree of success.

Both the tungsten arc and metal arc inert-gas-welding process are employed together with resistance welding in the fabrication of the aluminum air filters pictured in Fig. 55. The entire assembly consists of a spray tank (left foreground) upon which is mounted an angle framework which supports the filter cells proper and the larger blower fan. A conical sheet section encloses the framework.

The tanks are 6 1/2 ft. long, 5 ft. wide and 2 ft. deep with the bottom flanged to form the ends and then welded with the gas-shielded metal-arc process to the sides. All material is 3/16-in. 61S-T6 aluminum. In the welding the aligned sheets are tacked with the gun at 12-in. intervals and then completely fillet welded

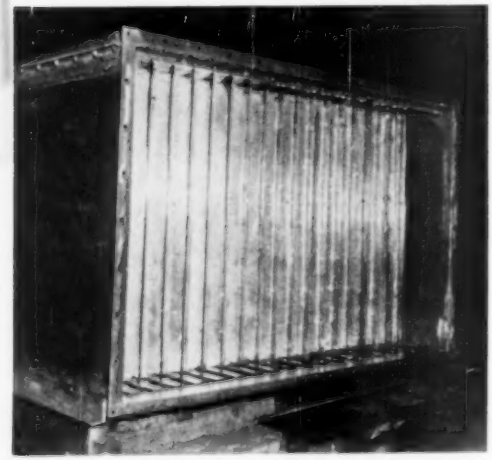

Fig. 56 Assembled sulphuric acid vapor separator. The gas flows horizontally through the baffles

first on one side and then the other. To make for easier cleaning of the tank while in service a larger than normal bead is run. Also the welding is done continuously, something possible with this process and the appearance is thereby enhanced. Aluminum angles are welded to the tank to support the feet.

When it came to welding the three connections shown on the side of the tank in Fig. 55, the lower speed of the tungsten arc process was used to advantage.

In all, there was over 23 ft. of welding per tank, yet the time for fit up, tacking and welding approximated 1 hr. per tank. Of the 120 so far completed none has leaked.

In the upper framework the tungsten arc process is

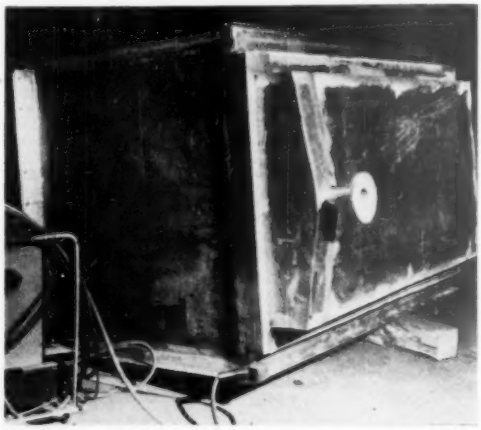

Fig. 57 Assembly tipped on its side to show the 61S-T6 welded aluminum acid pan

used to join the aluminum angles, and the sheeting is spot welded to it.

To have insisted on any one method of welding for this entire job would have increased the cost, but to use each dispassionately to its best advantage gave the fabricator and the ultimate user of these filters the best job at the lowest prices.

Another air filter, or specifically in this case, a device to remove sulphuric acid vapor from air shows further the scope of this new process. The acid laden vapors flow horizontally through the baffle nest in the casing shown in Fig. 56 with the entrapped acid collecting in a pan on the bottom. A better view of this pan (Fig. 57) shows the entire assembly tipped on its side.

The first part of this fabrication, the casing and pan, is fairly straightforward. All material is 61S-T6 1/4 in. and 3/8 in. thick welded with 1/16-in. wire. An interior view of casing ready for the baffles is in Fig. 58. The baffles, however, being of 12 gage 61S-T6 presented somewhat of a problem.

Each of the baffle plate assemblies is composed of 19 square hooked segments welded together to form a "washboard." Before starting this phase of the job, the operator put in several weeks of practice resulting in

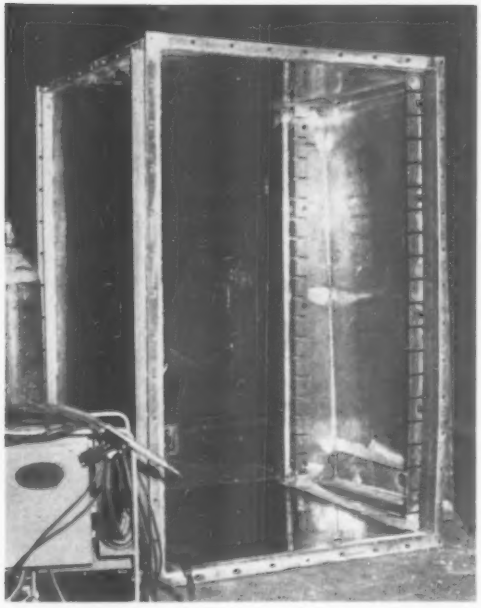

Fig. 58 Interior view of the casing ready for the baffle assemblies

the excellent welds shown in Fig. 59. Because of the light gage of the material, argon was used as the shielding gas in the amount of 40 cu. ft. per hour. Filler wire was $^1/_{16}$ in. 43S fed at 178 in. per minute and current 200 amp. To do the welding on two complete separators including all the baffles required 180 man-hours. To have used other methods would have increased the time and raised serious problems of distortion, but the Aircomatic, while having a very high specific rate of energy input, has a travel speed of welding so great as to confine the effects of heating to a narrow zone close to the weld. In addition to reducing distortion this also minimizes overaging effects in precipitation type hardening alloys such as 61S.

Fig. 59 Close up of baffles assembly of 12-gage 61S-T6 sheet. Argon gas used as shield because of thin material

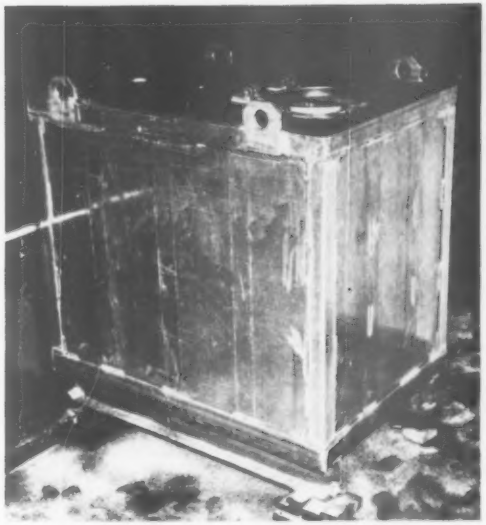

Fig. 60 Welded ink container for portable service of 61S aluminum. Size approximately 5 x 4 x 3 ft.

One of the earliest yet most successful applications came about because the builder of a number of tanks of this type shown in Fig. 60 was disturbed to find the welding time using the tungsten arc running around 280 man-hours per tank. Use of the gas-shielded metal-arc process provided some very interesting economies. For lightness, ease of cleaning and corrosion resistance,

Fig. 61 Welding the channel stiffeners to a side. Each 45-in. long, $^3/_{16}$-in. thick fillet takes $2^1/_2$ min. to make

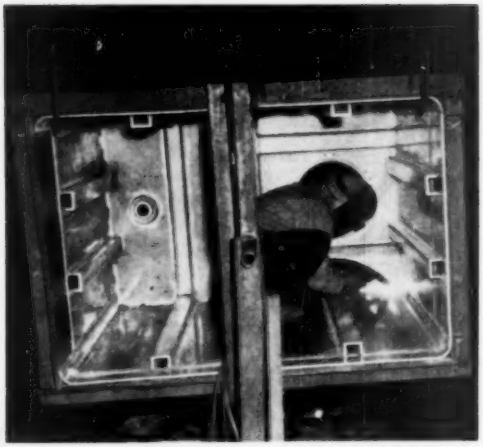

Fig. 62 Assembly parts in a jig. No positioning is necessary to complete the welding

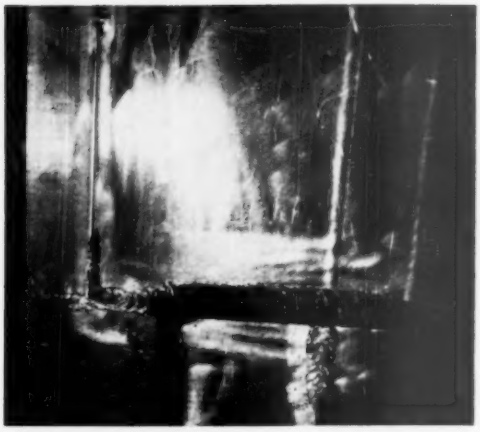

Fig. 64 This lifting lug is 6 x 7 x 3/4 in. thick. The fillet and butt welds joining it to the structure range from 3/4 to 1 1/8 in.

these approximately 5- x 3- x 5-ft. tanks are fabricated entirely of 618-T6 aluminum. Top, sides and bottom are 3/8 in. thick with the reinforcing channels, skids and lifting eyes in proportion. Over-all weight is 1000 lb.

Initial fabrication starts with the preparation of subassemblies of which a side is shown in Fig. 61. The side plate is clamped to the table and the reinforcing angles clamped on the plate. No tacking is required and the finish welding starts as soon as the assembly is positioned. The operator starts in the center and welds to the left edge; then goes to the right edge and welds to the center. The 5/16-in. fillet weld, 45 1/2 in. long, is made in 2 1/2 min. Immediately the welding table is put into the horizontal position, and the fillet weld for the other side of the channel is made by the same procedure and at the same speed. To make the foregoing welds, 1/16-in. 438 filler wire is used. Wire feed is 208 in. per

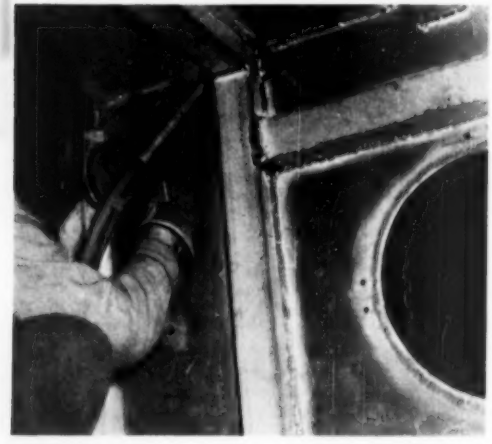

Fig. 63 Side butts are completed before welding on the top

Fig. 65 About 15% of the welding is tungsten arc and the time for welding is reduced to 48 hr. as compared to 280 hr. by the tungsten arc alone

minute, current is 210 amp., and the shielding gas is high purity helium at the rate of 45 cu. ft. per hour.

After completion of the subassemblies, all parts are assembled in a jig (Fig. 62) and completely welded prior to putting on the bottom. The side butts are completed before welding on the top in Fig. 63. In this connection, it is interesting to note that the jig is not positioned, whereas this was necessary when using the tungsten arc process.

Next the bottom is tacked on and welded completely inside and out with the tank in its normal position. A suction blower is used to insure the operator adequate fresh air.

An interesting detail is the lifting lug shown in Fig. 64. This pad is 6 x 7 x 3/4 in. thick. The fillets and

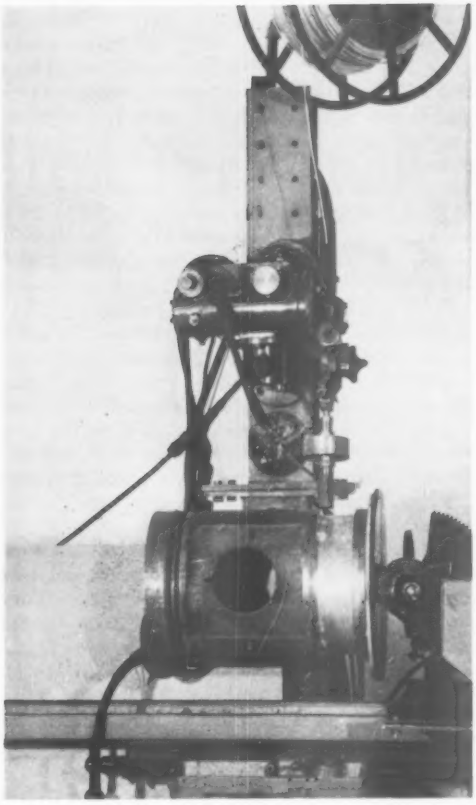

Fig. 66 Aluminum-wire alloy Diesel engine piston ready for rewelding by the aircomatic process

butts connecting it to the rest of the structure range from $^3/_4$ to $1^1/_8$ in. and are difficult to make in a reasonable time by any other method.

The over-all welding time per tank was reduced from 280 to 48 hr., of which about 8 hr. were clean-up welding by manual tungsten arc as in Fig. 65. The operator is using about 225 amp. of a.-c. current, a $^3/_{16}$-in. tungsten and argon as a shielding gas. This combination of the two processes—using each as it is best fitted to the job—resulted in the lowest over-all cost.

TYPICAL APPLICATION OF THE AIRCOMATIC HEAD

As America's railroads become dieselized, their maintenance problems change. Only a few years ago, there would have been little interest in the automatic welding arrangement shown in Fig. 66. Here a piston of a high strength and heat-resisting copper, silicon, nickel, aluminum alloy is having its worn areas rebuilt using an automatic version of the gas-shielded metal-arc process. As preparation for welding, the ring grooves were machined out leaving a cut about 3 in. wide and $^1/_2$ in. deep to be filled; an additional cut

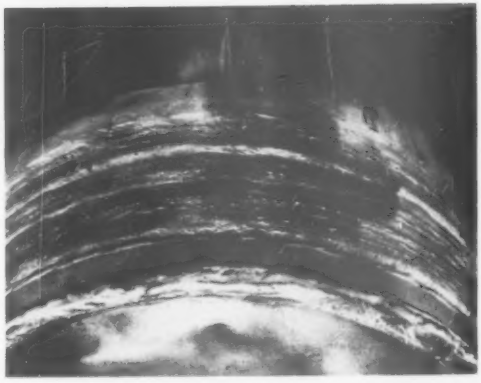

Fig. 67 Piston with completed weld

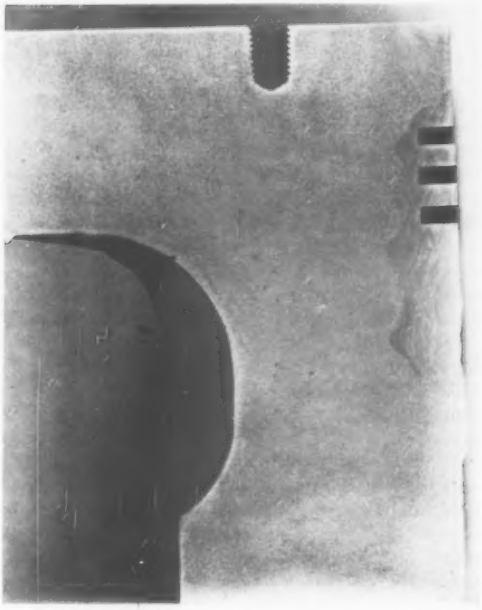

Fig. 68 Cross section of welded and machined piston

$^1/_2$ x $^1/_8$ in. was also taken along the circumference of the top of the piston.

On this job, $^1/_8$-in. wire is fed through a current pickup and a gas shield by an automatic head. The $^1/_2$- x 3-in. groove is filled by 30 passes at 25–35 v. and 330–420 amp. In order to avoid undercutting, the lower energy inputs are used at the ends of the cut. For most of the welding, helium gas flows of 100 cu. ft. per hour are sufficient. More is needed at the ends where the base metal is higher on one side of the gas nozzle than on the other. The necessary 6.5 lb. of metal were deposited in 45 min.

The groove at the top was filled in $7^1/_2$ min. using seven passes with the manual Aircomatic gun. The finished weld is shown in Fig. 67.

The completely machined and then sectional weld is shown in Fig. 68 which illustrates the character of deposit that can be expected.

SUMMARY

A method of inert-gas-shielded metal-arc welding has been developed in which unusual and new welding arc phenomena are combined to constitute a new welding process. This process uses bare electrode wire which is continuously fed to the arc where it is consumed and transferred to the base metal where it becomes part of the joint. The arc is shielded by an inert monatomic gas which flows from the nozzle through which the electrode also passes. The process has been applied to production work using manual and automatic equipment. Welding can be performed in all positions using the manual method. Welding speeds are considerably faster than other manual metal-arc welding methods. The arc is visible at all times and since fluxes are not used, no slag cleaning is required.

This process is readily applicable for welding many metals and alloys. This intrinsic property is the result of the inherent operational simplicity which permits the deposition of weld metal having the same chemical composition as the electrode wire; there are no gas-metal or slag-metal reactions in the welding operation. The principal consideration of a metallurgical nature involves alloying the electrode and base materials where these compositions are different. This alloying may be used to an advantage in many instances and the degree of alloying can be controlled by welding procedure.

All common types of fusion welded joints can be made in aluminum and its weldable alloys. The manual method is particularly adapted for making fillet welds in all positions. Well-shaped fillets can be made at the maximum speeds practical for manual welding. Butt joints should be designed to take advantage of the deep penetration characteristic to obtain maximum welding rates and minimum distortion. The mechanical properties of sound aluminum welds are the maximum that can be expected from the alloys used for welding and the metallurgical considerations involved. Gas porosity is an important problem in aluminum welding. Sound welds can be made in the flat position when proper welding procedures and techniques are followed. This process has been qualified for aluminum pressure vessel fabrication under existing code requirements. For many applications a reasonable amount of porosity is permissible because it has only a minor effect on weld strength. Several successful applications of this type have been described.

All of the commercial austenitic type stainless steels can be welded with the inert-gas-shielded metal-arc welding process. Butt joints and fillet welds can be made in all positions. The electrode wire composition used for welding the stainless steels must be controlled to prevent cracking. The ability to deposit weld metal of identical composition as the electrode wire used, permits joints to be made in which both weld and plate material have the same chemical composition, thereby minimizing corrosion and expansion problems where these factors are important. Titanium can be transferred through this inert-gas-shielded metal-arc and recovered to the extent of about 60% in the weld deposit. This enables titanium stabilized wire to be used for welding. Welding rates are higher and the mechanical properties of stainless weld metal deposits are equal or slightly superior to those obtained with coated electrodes. Spatter and vaporization losses average less than 1% of the wire melted.

The process has been found to be excellent for welding, braze welding and surfacing with aluminum bronze. Overlays of aluminum bronze on steel, copper, cast iron and manganese bronze are sound and are bonded securely. In the case of mild steel overlays, the bond strength is greater than that of the plate material. Aluminum-bronze electrode wire can be used for welding aluminum-bronze plate and other material in the vertical and overhead positions.

This inert-gas-shielded metal-arc process has been successfully used for welding clad steels and heat resisting metals of the gas-turbine type. These applications illustrate the versatility of the process for welding unusual materials where rigid control of the deposited weld metal analysis is required. The inherent simplicity and flexibility of the Aircomatic process opens many new fields for fabrication by welding. It is not expected that this process will supplant existing welding methods, except for those applications for which it is better suited.

ACKNOWLEDGMENT

The assistance and cooperation of staff members of the Research Laboratories and the Technical Sales Division of the Air Reduction Co. are gratefully acknowledged. Thanks are also extended to the welding staff of Battelle Memorial Institute. Without the cooperation and sincere effort of the many individuals involved, the information herein reported could not have been presented in such detail.

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Trends in Fabrication by Welding

Plate fabrication requires careful consideration by department heads including selection of materials, design, fabrication procedures, production schedules, testing and cost accounting

by S. V. Williams

THE purpose of this paper is to study and analyze the trends in fabrication by welding, with hopes of stimulating thoughts on the subject so that these thoughts can be crystallized out into a general procedure for "Fabrication by Welding" which will be of help to all who are interested in improving the quality of their fabrication by welding, and in this way help to stabilize the industry.

Fabrication, as used in this paper, means the art of creating metal structures, vessels or products out of many metal pieces or parts.

Welding, as used in this paper, means the coalescence or growing into one body, of the meeting edges of the metal pieces or parts, so as to establish a structure which will meet the specifications and will function as well or better than the constituent parts specified.

This implies that fabrication by welding permits the structure or vessel or final product to be made as strong and stable as its metal parts or materials being used or fabricated. Good design and engineering is based on utilizing fully the inherent, stable properties of the materials being used. Those properties which, through years of testing and usage of these materials under varying atmospheres and temperatures, have been found resistant to change, and therefore, are spoken of as being reliable and stable. Certainly fusion welding has proved itself reliable and stable, and hence it is recognized as the way to fabricate metal structures. Therefore, the trend is now toward stabilization of the industry that uses welding as a means of fabricating useful products so that it can render greater usefulness to man in his upward struggle.

MATERIALS IMPROVED THROUGH WELDING

The most economical material for the large bulk of our fabrication is steel with its various analyses. This does not mean that other metals are not giving steel competition. Modern welding has fostered not only the improvements in commercial steel plate but also many of the nonferrous metals and their various alloys, which can be fabricated by welding. For, when once the full physical properties of any material can be fully utilized when fabricated, American engineers develop a better material. Here in America we have that freedom and opportunity of competition that fosters good engineering. The economic force of competitive industry demands good engineering and our farsighted industrialists have fostered schools and societies to continually train men to meet this demand.

The trend in fabrication is toward the use of the best materials available. This means that the fabricator, to meet competition, must know about the best materials available—know about their chemical and physical properties, so that these can be used in component parts where these improved properties can be utilized economically in a fabricated structure. Such parts, whether unfinished, semifinished or finished, must be reliable and stable, for welding is an inspection process which exposes, develops and reveals weaknesses in the materials being fabricated. If such weaknesses are ignored by the fabricator, the final product will generally not pass the acceptance tests and will definitely be found wanting in service. In short to withstand modern fabrication, the materials being fabricated must be sound and stable.

Good fabricators have come to realize that welding is not a substitute for faulty materials, that, in most cases, if carried on correctly, it will reveal all faulty material. The trend is now for the suppliers of material for fabrication by welding to caution the fabricator if the material is not a suitable material for his welding. In short, welding has definitely improved and increased the number of engineering materials available to the American Engineer for his use in designing process equipment, etc.

DESIGN MUST BE COMPLETE & ACCURATE

In most cases welding has enabled the designer to simplify his designs, and streamlining of fabricated products has become the general trend.

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Such welded designs eliminate the high concentration of stresses and thus help create a more stable product, that gives greater assurance of a longer and more continuous life of usefulness for the product thus made. In many cases this has meant that processes which would be commercially uneconomical to operate, because of high-maintenance costs and loss of operation and, therefore, production, become highly successful when their equipment is fabricated by welding. The trend is toward fabrication of all equipment by welding, in the processing industry.

The growth of welding as the best means of fabricating equipment, was greatly fostered by World War II In short, it was our life line during the war, and is our best assurance for greater freedom in the future. For welding typifies our American way of life, like all great things in America, and America itself, it never thrives on past glory. The trend is toward greater perfection in the industry, starting with the engineering and following through to the completion of the structure, for delivery at the date promised.

The recent trends in fabrication by welding at the writer's plant have taken into consideration those factors that practically affect production costs of quality finished weldments. Since the war, the commercial tolerances on materials have been at their widest limits or extremes, and in many cases, slightly beyond border line acceptance. Yet with welding, we accepted them. This meant that the estimator and designer who figured on straight, square or flat parts or structurals to be used as-received, found out that a finished assembly of such parts would not meet the tolerances anticipated. To meet the tolerances required on most weldments, extra work had to be done at the start to establish acceptable dimensions on all component parts, if low-cost manufacturing was to be carried on. In short, it has been established that welding is not a cure-all for faulty materials either of a physical or dimensional order, if low costs are to be established. This fact has taught the estimator, designer and production department the value of knowing what they are starting with or building upon, if costs are to be in line. In short, good manufacturing practices should start with the engineers and estimators and take into consideration the current and actual factors that enter into the fabrication of quality low-cost weldments. The estimators and designers have no more right to guess and assume things than the production department, if the most economical design is to be created and produced. If these factors are overlooked, or commercial tolerances taken for granted, high costs, poor workmanship and delayed deliveries will result, with monthly shipments under those estimated and dissatisfied customers. Competition permits the customer to do something about this in America. Good management must meet this challenge of competition.

This has fostered and led to the following standard practices in designing and engineering.

1. Start with good weldable materials, not necessarily the cheapest, and allow enough for finishes where required.

2. To design and engineer the weldment in the drafting room is more economical than to leave the designing and engineering to be carried out by trial and error on the production floor, where overhead or burden rates are higher for each man-hour consumed.

3. Production drawings should not have unfinished details to be worked out in the layout department, unless these details are covered by standard detail drawings. In which case, reference should be made on the production drawings to the standard detail drawing.

4. The production drawings should be clear and readily interpreted and readable. Paper should not be conserved at the expense of clearness.

5. Designers of weldments can best perfect their designs by spending some time each day in the shop, observing the concrete objects they have imagined and visualized in the abstract form. This enables them to more accurately visualize their design. If they are hazy on a detail, do not leave that detail for the layout man to work out. Go down and talk it over together. This will help prepare him and all will profit, particularly your company in meeting future competition.

6. The design must allow for shrinkage and finish. Do not skimp on material. To minimize this, the meeting edges of component parts should, wherever possible, permit adjustments to be made for this shrinkage in the sequence of welding and assembly or fit-up.

7. The modern designer must eliminate all factors of ignorance on his drawings. If there is uncertainty, this must be cleared up before estimating. Certainly before the drawings go to the shop where production hours carry overhead burdens. In other words, it is less expensive to use an eraser and drawing tools than to re-work with gas cutting and welding, parts or assemblies made to a misleading drawing. As one illustration, if an assembly must be machined and held to a close tolerance, the designer should call for a stress-relieving operation. This to assure that the factor of ignorance as to the amount of locked-up stresses in the weldment is reduced to a minimum. This is a designer's problem, not the production man's. The production man may not even surmise the finished machine tolerances are to be close.

8. Both estimators and designers must take into consideration the tools and equipment available in the shop, and figure out the best design to use this equipment to the best advantage.

9. Good designing means complete designs and complete engineering.

Let us all face the facts, since it is generally recognized that the free enterprise system is being challenged by the controlled or totalitarian system. This means that you and I are being challenged in our way of doing things, in our way of carrying on our free enterprise. If we do not improve our system, we may not meet this challenge or even the competition of our free enterprise system. As free individuals, let us think our problem through correctly, even though our system permits us

to make a mistake and still have another chance if our intention was good. We must correct our thinking, if we are really endeavoring to improve our way of life and the free enterprise system.

PROCEDURE MUST BE SETUP & FOLLOWED

With this in mind we are suggesting a general procedure for fabrication by welding, which should help to eliminate all the guessing possible from a business made competitively hazardous to all fabricators who do such guessing. Plate fabrication is a job-lot production business. Repetitive production does not come frequently enough to enable skills and setups to be carried over and on by force of habit. Each job must be thought through and planned completely to eliminate foolish quoting of prices and deliveries. Such quoting generally results in losses to both the fabricator and the customer, and the free enterprise system cannot tolerate this.

The finished job must meet dimensions and specifications stipulated by the customer and regulatory bodies. This cannot be successfully carried out by guessing. In other words, the actual production workmanship must meet these requirements, hence the workman in the shop and all departments along the line must be given accurate information to plan and work with. In short, we should expect no more or less of the production department than we do of each department responsible for furnishing fabricating information for accurately fulfilling the contract. For only accurate abstract information will help transform the customer's demands into accurate, concrete, acceptable products that will function safely and economically when placed in service, and hence make for repeat customers.

Likewise, procedures must be set up, as planned in estimating the jobs, and these procedures carried out in fabrication if the estimated production hours and deliveries are to be met. In turn, these procedures and methods must be as detailed and accurate as commercial practices will permit, with tools available.

Guessing and passing the responsibility must be reduced to a minimum on the part of all departments. Facts and accurate information are as essential as the reliability of the materials one is fabricating. And for all who sit at the head places, they should remember that a dying fish stinks at the head first. The production department often is the scapegoat, as it has to make actual deliveries.

With hopes of helping in correcting some of these conditions in the industry, and helping the production department make shipments, the following general procedure is submitted as the trend for more stability in "Fabrication by Welding":

PRELIMINARY ENGINEERING

1. Inquiries should be reviewed and credit established; if desirable for production facilities and capacities, accepted and assigned inquiry number, then forwarded to the engineering department.

2. Engineering checks and if the most economically designed for shop equipment, and sufficient engineering information is available and codes complied with, the inquiries are then sent to the estimating department.

3. If preliminary engineering required, engineering department must furnish same so estimating can be carried out accurately and speedily.

4. Estimating department should use standards available and agreed upon by all departments.

ESTIMATES MUST BE BASED ON FACTS

5. For estimating, work specification, bill of material and drawings must be available for figuring, otherwise guessing results will make competition that much harder and estimating costs high in the end. The following breakdown is the minimum that should be made in estimating:

- 5.1 Material, flat and formed. Type, grade, size weight and costs.
- 5.2 Layout, flat and assemblies. Man-hours.
- 5.3 Forming, pre and final. Man-hours and facilities used.
- 5.4 Fitting, details and assemblies. Man-hours and special jigs.
- 5.5 Welding, manual and machine. Man-hours and special electrodes.
- 5.6 Assembling, detail and assemblies. Man-hours and fixtures.
- 5.7 Machining, pre and final. Man-hours and set-up time.
- 5.8 Finishing. Man-hours and special equipment.
- 5.9 Stress relieving. Weight, time and temperature equipment available.
- 5.10 Inspection. Special for insurance, etc.
- 5.11 Testing, hydrostatic and nondestructive. Man-hours and special equipment.
- 5.12 Final release and shipping preparations. Man-hours required and equipment for handling and cleaning, painting and closures and cost of crating, skids or dunnage.

Essentially the entire scheme of fabricating should be considered in the estimating, together with productive hours available in different departments as enumerated above, as delivery promise is a most vital factor in quoting and securing repetitive business, as competition does not permit continuous guessing.

Estimates vs. Orders

6. Successful quotations indicated by a bonafide order must be checked against the customer's order received, or vice versa, before said order is released to order department for processing. This check to cover:

- 6.0 Status of credit.
- 6.1 Specification for material.
- 6.2 Design drawings changes.
- 6.3 Code and regulatory body restrictions.
- 6.4 Finish and painting.
- 6.5 Packaging and routing.

7. Drawings suitable for producing a finished product meeting the customer's specifications and Code requirements must be made by the design engineering department and approved by customer.

8. Requisitions issued by the engineering department to all other departments responsible for securing all materials specified and required to meet dimensions for fabrication, testing and customer's operation. In short, material to make the products specified on customer's order.

9. A complete bill of material giving sheet and item number and procurement information on each item. This to be used by all departments in carrying out their duties in placing order in production and following same through all phases of fabrication.

10. Purchase and stores orders to be placed in the hands of the production department so that they can designate where, when and who shall be responsible for checking same to see that they meet bill of material dimensions and requirements, and can be released for manufacturing as needed with no delays or hold ups when once processing is started.

11. Production schedule should be set up based on production hours estimated (5), and availability of material (10–13), so that when once fabrication is started no hold up of material in production space will tie up facilities located therein.

12. Each order must be so planned that parts, assemblies and subassemblies flow toward date and position or space required for final assembly. Production spaces cannot be taken up as storage space if efficient production is to be maintained with facilities available.

QUANTITY CONTROL

13. Quantity control of production must be through a breakdown of production hours set up in (5) by the estimating department, as applied to the scheduling of orders based on date of receiving materials and the facilities available in the shop. This assumes a fluid supply of productive labor hours to be maintained by increasing hours per day and week, or increasing personnel to the limit of facilities available in the shop. This in turn must take into consideration the backlog of productive hours, and the economies of overtime vs. additional shop space and facilities. All factors, as in estimating (5), must be taken into consideration. Namely:

13.1 Complete layout of space and facilities for fabrication by departments and subareas.

13.2 Complete knowledge of space available for storage of incoming materials, parts and subassemblies.

13.3 Nonproducers available to service and supervise productive work.

13.4 Layout man-hours available for laying out flat, formed parts, assemblies, subassemblies and final assemblies.

13.5 Hours and equipment available for dimensioning and edge preparing plates, parts, assemblies and subassemblies.

13.6 Man-hours required and available for forming by gas cutting, machining, rolling, breaking and press forming, hot and cold flanging of flat work, part assemblies and subassemblies.

13.7 Man-hours available for fitting of pieces, parts, assemblies, subassemblies and final assemblies.

13.8 Man-hours available for both automatic and hand welding of X-ray and nonX-rayed work on parts, assemblies, subassemblies and final assemblies.

13.9 Man- and machine-hours available for X-ray and re-X-raying of welding requiring same.

13.10 Man-hours required for final finishing, including machining, sandblasting, passivating, magnaflux, etc., and assembly work when required.

13.11 Hours and equipment for stress relieving and heat treatment of parts, assemblies, subassemblies and final assemblies.

13.12 Man-hours and equipment available for hydrostatic testing of parts, assemblies, subassemblies and completed assemblies.

13.13 Man-hours and space available for preparing for shipment, such as painting, greasing machined surfaces, crating, boxing, skidding and protecting parts for shipping.

13.14 Man-hours available for loading and blocking final jobs on and in cars or trucks.

14. Production lines or space must have materials, parts, subassemblies, etc., delivered to stations designated, so fitters, welders, machinists and assemblers can perform the operation next in sequence. This implies that all previous operations performed have been correctly carried out, and that inspection has checked and released same for further fabrication. Expeditor must work closely with production progress.

QUALITY CONTROL

15. Quality control of fabrication must be maintained by inspection, this does not mean that production can ignore drawings, specifications and dimensions. The inspection department does not write the specifications or set the requirements. They work from the same engineering drawings and specifications that production must follow. Inspection is set up as an independent agency to check material and workmanship, and give greater assurance that the finished products meet the drawings and specifications stipulated on the order. Inspection must not hold up production, yet must correlate its work so that production can go ahead when all previous operations are correctly performed on acceptable material.

When errors are made, rejection slips must be issued and a charge number established to charge the time and material that is necessary to perform extra work in correcting such errors. In other words, the inspection

department is the referee. They must call the errors as they see them, and realize that in doing so they are only protecting the Company's interest. The inspectors are competing with someone else in another plant doing the same type of inspection work, and if their company is to be successful in competing with other companies doing the same type of work, they must be accurate in their work and decisions. This applies to all departments from the head down to those on production.

16. By following out the procedure outlines in (15) correct time can be taken of the actual operations. With corrections made for errors and mistakes, the corrected time can then be used by the estimating department on any duplicate operations. This will enable the estimating department to establish more standards, and be more accurate in their quoting. This should be wholesome for fabricating in general.

In addition to the above, the rejection slips can be used by management to evaluate the true performance of each department and the workers therein. This will show weak spots that need attention and strengthening.

17. To assure the continuous flow of production, and the meeting of scheduled deliveries and shipments, meeting of department heads must be held to expedite the flow of information on corrections or changes to the production planning, and swift carrying out of the executive orders of management. At such meetings only the concrete facts affecting production are to be presented.

18. Independent of meetings in (17) progress reports by each department head should be submitted weekly to those meetings in (17). These can be read and studied outside of working hours. The value of same being to help the writers to think and express themselves better, organize and plan their work ahead and eliminate waste discussion and time at production meetings in (17).

CONCLUSION

It is believed that this general procedure for plate fabrication should be read, studied and analyzed by all department heads of all fabricating companies, so that the final form they use will be the crystalized thoughts of all who must follow and work with such a general procedure. In this way it should be as complete and accurate as commercial practices will permit. Competition fosters this in the free enterprise system. The trend in fabrication by welding, is toward stabilizing the industry, so that it will continue to improve under the free enterprise system, and thus truly meet the challenge of our time, namely socialized industry, controlled by the state.

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PRACTICAL WELDER AND DESIGNER

Production Butt and Flash Welding

Automatic control over welding cycle and selective annealing heats, expedite and guarantee efficiently fused or arc-welded joints all depending on type of equipment used

by H. J. Chamberland

BUTT welding sawbands or band stock and steel tape automatically is not an innovation, however, the process was for more than a decade limited to a practical 1/2 in. width and a thickness never exceeding 0.040 in. A few years ago the butt-welding device was improved to execute a fused joint 5/8 in. wide, however, what really extended its field of applications was the addition of auxiliary Vee jaws to provide facilities for welding extensions to tools as in Fig. 1. With the recent development of the flash welding unit it is now possible to weld bands up to 2 in. wide and 1/16 in. thickness, or flat stock of similar dimensions as shown in Figs. 2 and 3, respectively.

In this highly competitive age, the original cost of any type of equipment is secondary to the extent of its productivity, the quality of work it will deliver and its versatility All three factors combine to determine how soon the machine, device or instrument will liquidate itself since this is the prime objective of any investment along lines of modernization. As to choice of welding units herein concerned both are adapted to rod welding, with the butt welder preferably limited to light rods or wire work as in Fig. 4 and bands under 5/8 in. wide. For wider bands or rods up to its 5/16-in. capacity, the flash welding unit is not only recommended but is imperative for maximum results since its transformer capacity is 8 kva. or twice that of the butt welding unit.

Flash welding is however fast becoming the industrially accepted method of joining sawbands because accuracy and strength are essential regardless of width and operating velocity. The fact remains that the importance of weld efficiency increases with increased blade width and speed. As for example, it is obvious that a 2-in. band resawing in two a 2- x 8-in. plank at 6000 fpm. or a 1-in. band friction cutting 3/4-in. boiler plate at 15,000 fpm. with heavy work feed, requires a weld far more secure than a 1/2-in. band operating at a 100 fpm. and only subjected to limited work pressure.

Sawband costs as a whole are kept at a minimum by cutting the bands to length from 100- or 500-ft. coils and doing the welding on the job. All contour sawing machines, Fig. 5, have inbuilt automatic saw welders; otherwise, a portable or pedestal type unit will take care of all saw welds and other applications in the plant within its fusing or arc-welding range.

The most accurate and strongest weld is one, although discernible, that incorporates the same internal and external characteristics as any other section of the band.

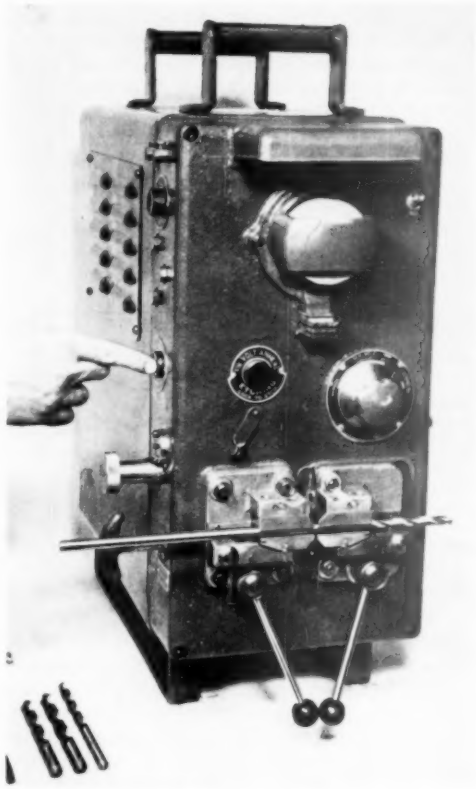

Fig. 1 Portable type butt welding unit of 4 kva. transformer capacity adapted to sawbands or flat stock no wider than 5/8 in. and to rods preferably under 3/16 in. in diameter

H. J. Chamberland is Research Engineer, The DoAll Co., Des Plaines, Ill.

Maximum efficiency in this respect is based on three requisites. First: Automatic control of the actual welding cycle. Second: Selective annealing heats as predetermined on the basis of width and thickness of band or flat stock, or corresponding area. Third: At least an elementary knowledge of the effects of said heat on the completed weld. It should be mentioned before we proceed further that rod welding does not differ from band welding except for allowing a $^1/_{16}$-in. gap between the parts. This distance has been determined as most practical to provide the correct pressure for coordination with the predetermined advancing distance of the movable electrode.

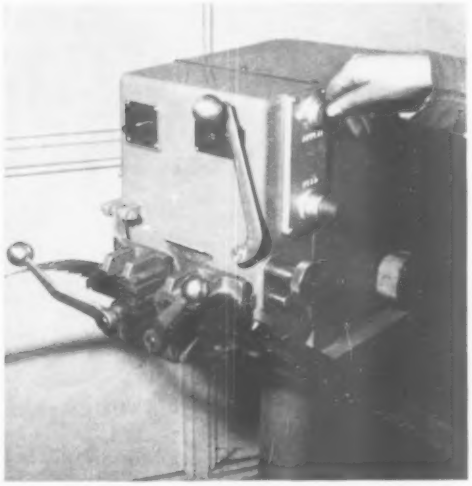

Fig. 2 Annealing weld on $1^3/_4$-in. wide wood cutting band, this flash welding unit has a capacity of 8 kva.

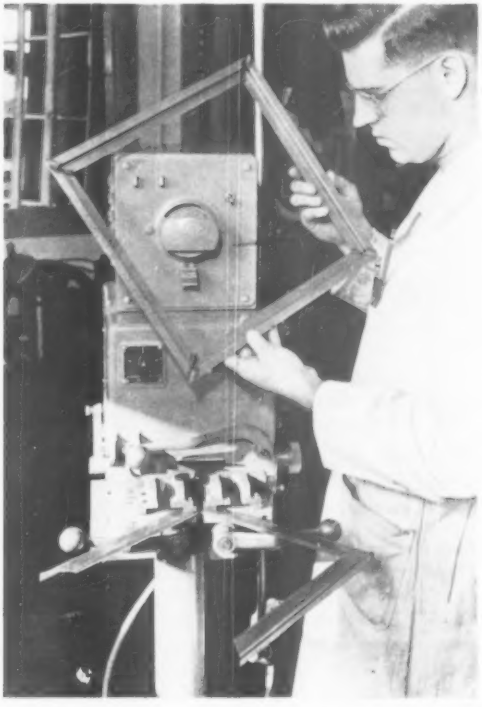

Fig. 3 Flash welding $1^1/_2$- x $^1/_{16}$-in. stock, this welder will also weld rods up to $^5/_{16}$ in. diameter

Fig. 4 Typical butt welding applications, from 25 to 30 complete welds per hour are common production results

WELDING

Regardless of the fact that the welding cycle is fully automatic, and for the same reason that one would not attempt to drill two holes spaced precisely from a steel rule layout, certain advanced measures are imperative in support of the actual welding operation. The ends to be joined should be polished back to a distance of $^3/_4$ in. for removing all scale and other foreign matter. Perfect alignment of the surfaces is highly important, the ends of bands should preferably be squared with a guillotine type shear or if hand ground a square should be used. Of course the necessity to accurately align both back edges of the band against the back edge of the welding jaws or electrodes, previous to clamping, need not be emphasized.

Automatic welding requires but three major steps: Pressing the welding switch. Pressing the annealing switch. Removing the flash on the welder grinding wheel to fit the proper thickness gage if a band is concerned. The amount of heat required and advance of movable electrode vary according to width of band and related adjustments are readily made previous to pressing the welding switch, after which the current is automatically cut off in due time. Thus far there is no cause to worry providing aforesaid prewelding pre-

Fig. 5 Flash welding 1-in. wide friction sawing band in inbuilt welder of modern contour sawing machine

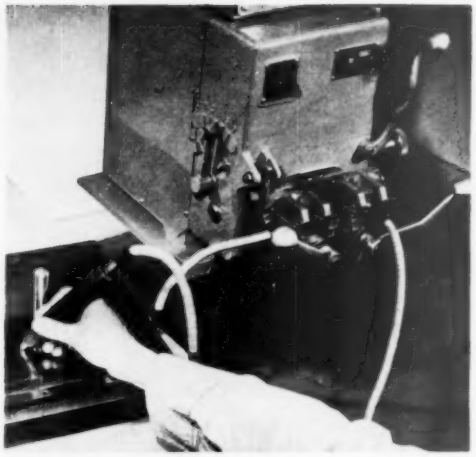

Fig. 6 Etching pencil being used in connection with flash welder

cautions have been kept in mind, however, if there is any doubt as to the structure of welds on the wider saws, all one has to do is to allow the weld to cool and then break it. A fine grain structure resembles that of a broken file and denotes a strong weld. A coarse grain structure appears like thousands of minute crystals, such a weld is therefore brittle and already defective before annealing. It is far better to increase the advancing distance of the movable electrode and thereby increase the flash, than risk a worthless coarse grain structure and a weld that will resist flexing for only a short duration.

ANNEALING

Setting the dial for the correct amount of annealing heat based on width and thickness of band is simple, however, timing that heat to the second and not being deceived by the color is the essential part of the job.

Experience along these lines has shown that an annealing temperature of from 950 to 1100° F., will reduce hardness sufficiently to prevent any tendency toward rehardening or embrittlement of the weld caused by a too rapid cooling rate. Proper annealing temperatures can better be obtained by joggling the annealing switch button, Fig. 2, this will give the weld short surges of heat of 10 to 20 sec. duration or until the glow appears as a very faint blood red. This color should positively not be allowed to become brighter. It is also well to bear in mind that the glow from the heated section will not become visible in a brightly lighted room, until a temperature of 1200° F. is reached and this is definitely too high a heat. Consequently, some means of shading the weld should be used to darken the room for the glow to become apparent at 950 or 1000° at the most.

It is understood that even a foolproof welding unit, insofar as design is concerned, will not function correctly if fluctuation in loads through improper line voltage causes the actual voltage of the welder to vary on the high or low side during the welding operation. To help overcome this condition, late type flash welders are provided with a voltmeter selector switch and special transformer with 160, 180, 200, 220 and 240 volt taps. The voltmeter and tap switch are mounted close to the welding switch button on the side of the case, with wires of sufficient length for removing the case without interfering with the wiring. With this arrangement, assuming that the wiring to the welder is adequate, the operator can readily check the line voltage available at the welder and select the closest corresponding tap and thus compensate for voltage variation to suit blade width, rod diameter, etc.

Either the butt or flash welding unit is readily converted to an economical tool marking instrument by simply plugging in the etching pencil attachment shown in Fig. 6.

Vierendeel Trusses

THE accompanying photographs, Figs. 1 and 2, are reproduced from an article by A. Bozzarelli of the ILVA firm in Italy, appearing in the November 1949 issue of *L'Ossature Metallique*. In July 1939, Prof. Vierendeel wrote to the author congratulating him for making the first application of Vierendeel trusses to large structures other than bridges. The Vierendeel truss has no diagonal members, and is calculated in accordance with Prof. Vierendeel's published methods. The actual degree of rigidity has been shown by tests to be only 5 to 6% less than calculated.

The Vierendeel truss is particularly suited to welding. The steel for the trusses in Figs. 1 and 2 had the following properties:

Elastic limit = 33,000 psi.
Tensile strength = 60,000 to 71,000 psi.
Elongation = 20 to 25%

The steel used in the truss in Fig. 1 was basic Bessemer steel, which required some riveted connections to hasten fabrication. The steel for the aerial railway, Fig. 2, was electric furnace steel, and no riveting was required.

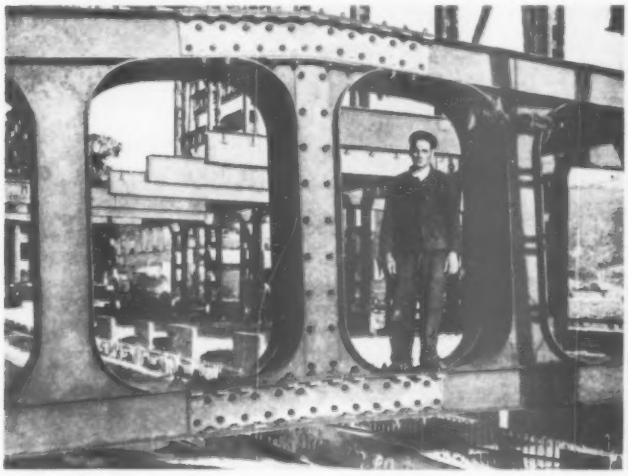

Fig. 1 Detail of a Vierendeel truss in Naples

Fig. 2 Vierendeel trusses in an aerial tramway

Welding Galvanized Iron

Knowing facts about zinc coating helps you get good results

by F. J. Pilia

WHEN iron base metal is dipped in a bath of molten zinc, a coating of zinc forms on the surface of the base metal. The metal then becomes galvanized iron and is resistant to corrosion. It can be fusion welded or bonze-welded in exactly the same way as similar uncoated material. However, unless you know a few facts about the zinc coating you may have some difficulty.

F. J. Pilia, The Linde Air Products Co., Newark, N. J.

Zinc has a low melting point. It also turns to a vapor when you heat it. This means that when you heat galvanized iron, as in welding, the zinc coating does not run on the surface. Instead, it burns, and forms white fumes of zinc oxide.

Fig. 1 When galvanized material is joined by fusion welding, the heat of welding burns the zinc coating off as shown here

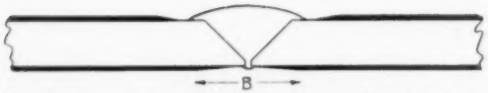

Fig. 2 Since bronze welding requires only a low heat, less zinc coating is burned off. This is shown by the distance B

Inhaling these fumes can make you sick. Welding galvanized iron should therefore be done in well-ventilated places. If you cannot work outdoors, wear a suitable respirator or drive the fumes away by means of a fan.

The edges of the joint to be welded should be thoroughly cleaned. Remove any oil, dirt or grease from the joint, but do not remove the coating. It is only about 0.001 to 0.005 in. thick so do not use a file; use steel wool or fine emery cloth.

WELDING METHODS

Since the zinc coating melts at a low temperature welds should be made with the smallest amount of heat necessary for good fusion. The less welding heat you use, the less coating you will burn off.

Bronze welding (braze welding) is best for joining galvanized material because it requires less heat than fusion welding. Therefore, a smaller amount of coating will be burned off. A flux-coated bronze rod is ideal because it speeds the bronze-welding operation and reduces the chance of overheating.

Fig. 3 Bronze welding provides an ideal method for joining these special corrugated galvanized iron fittings

POINTS TO REMEMBER

The only difference between galvanized iron, and plain iron is the zinc coating. It is put on to prevent rusting, so do not take it off. Use a welding head that is the right size for the job, and make the welds quickly, smoothly and in well-ventilated places.

A Hint for Hard Facing

by E. H. Frail

ONE way to get a sharp, square edge when you do hard facing is to deposit the hard-facing alloy so it hangs over the edge. Then you can square it up when you do the grinding. But, if the alloy overhangs too much you will have a tough grinding job.

Grinding time can be cut by "plastic wiping." Figure 1 shows the edge of a part that has been hard faced. This has a good overflow of metal, but the grinding will take a long time.

E. H. Frail is connected with The Linde Air Products Co., New York.

Reheat about 2 to 2½ in. of the hard-facing alloy along the edge until it starts to get soft. Hold the blowpipe so the flame points directly at the edge, as shown in Fig. 2. When the metal becomes plastic, hold a piece of hard-facing rod or steel welding rod against the side. Then slide the rod along the soft metal and "wipe off" the excess. Repeat this operation until the entire edge has been straightened up. Be sure to heat only 2 to 2½ in. at a time.

The excess hard-facing alloy you have wiped off can be used again. Melt it onto a grooved steel plate or length of angle iron. When it cools you will have a rod you can use on another hard-facing job.

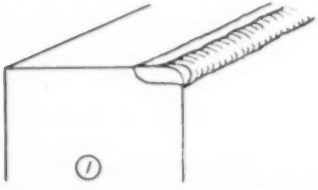

Fig. 1 Grinding a square edge is a tough job when the hard-facing alloy hangs over the edge like this

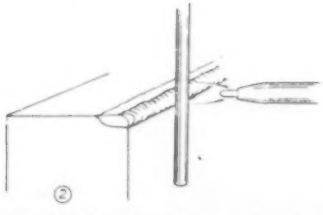

Fig. 2 Point the flame at the edge until the metal becomes plastic, then slide a rod along the side

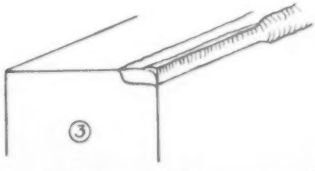

Fig. 3 Here part of the excess metal has been wiped off, this cuts down on grinding time

the AMERICAN WELDING SOCIETY

activities • related events

Nomination for Officers, Board and Nominating Committee Members

The Nominating Committee of the AMERICAN WELDING SOCIETY selected the following officers and directors for the term commencing October 1950:

President, H. W. Pierce, New York Shipbuilding Corp., Camden, N. J.

First Vice-President, C. H. Jennings, Westinghouse Electric Corp., Buffalo, N. Y.

Second Vice-President, F. L. Plummer, Hammond Iron Works, Warren, Pa.

Treasurer, R. S. Donald, R. S. Donald, Inc., N. Y. C.

Directors-at-Large: La Motte Grover, Air Reduction Sales Co., N. Y. C.; H. E. Rockefeller, The Linde Air Products Co., N. Y. C.; J. R. Stitt, The R. C. Mahon Co., Detroit, Mich. and C. B. Voldrich, Battelle Memorial Institute, Columbus, Ohio.

The District Nominating Committees of the AMERICAN WELDING SOCIETY selected the following District Vice-Presidents and District Representatives on the 1950–51 National Nominating Committee:

District Vice-President: *No. 2* (Mid-Eastern), A. G. Bissell, Bureau of Ships, Navy Dept., Washington, D. C.; *No. 4* (Central), T. J. Crawford, Consulting Engineer, Berkley, Mich. and *No. 6* (Mid-Southern), A. E. Wisler, Hughes Tool Co., Houston, Tex.

District Representatives on 1950–51 National Nominating Committee: *No. 1* (New York and New England), C. E. Jackson, Union Carbide & Carbon Res. Labs., Niagara Falls, N. Y.; *No. 2* (Mid-Eastern), Louis Ames, Air Reduction Co., Philadelphia, Pa.; *No. 3* (Southern), D. H. Curry, Chicago Bridge & Iron Co., Birmingham, Ala.; *No. 4* (Central), J. R. Stitt, The R. C. Mahon Co., Detroit, Mich.; *No. 5* (Mid-Western), W. G. Fassnacht, Bendix Products Division, Bendix Aviation Corp., South Bend, Indiana; *No. 6* (Mid-Southern), A. K. Pandjiris, The Pandjiris Weldment Co., St. Louis, Mo. and *No. 7* (Western), Charles L. Haynes, C. F. Braun & Co., Alhambra, Calif.

Nominee—President

HARRY W. PIERCE

Harry W. Pierce graduated from the United States Naval Academy in 1922, postgraduate in Naval Construction from Massachusetts Institute of Technology 1925–26. He served as Naval Constructor, U. S. Navy until 1930. Has been connected with the New York Shipbuilding Corp. since 1930. Most of his work

Harry W. Pierce

during eighteen years has been closely connected with welding in ship construction. At present he is Assistant to the President.

Mr. Pierce is a native of Nebraska, and started out studying chemistry at the University of Nebraska before World War I diverted him into the Navy. During the war years, in addition to his duties at the New York Shipbuilding Corp., Mr. Pierce handled several projects for the Bureau of Ships, Navy Dept., and received the Certificate of Commendation of the Bureau of Ships. Also one of a Special Committee for the investigation of the Tanker *Schenectady* in January 1942, and has since served on many Advisory Committees in connection with the investigation of welding stresses in ships, steel for ship construction and corollary investigations.

In 1947 Mr. Pierce was granted a four months' leave of absence from New York Ship to join Overseas Consultants, Inc., for a study of the Japanese Shipbuilding industry for the War Dept., in connection with reparations and determination of minimum industrial levels in shipbuilding.

He was Vice-President of District No. 2 of the AMERICAN WELDING SOCIETY, having previously served as Chairman of the Philadelphia Section, Chairman of the Marine Committee, Chairman of the Technical Activities Committee and as a Director-at-Large.

Mr. Pierce is also a member of the Society of Naval Architects and Marine Engineers, the American Society for Testing Materials, Director of the Engineers' Club of Philadelphia and honorary member of the Japan Welding Society.

He is Vice-President of the Engineers' Club of Philadelphia, and President of the Philadelphia Maritime Society

Mr. Pierce has also served the SOCIETY as 1st and 2nd Vice-President and is currently a member of the Board of Directors and Finance Committee.

Nominee—1st Vice-President

CHARLES H. JENNINGS

Charles H. Jennings was born in Des Moines, Iowa, Jan. 23, 1906, and attended Iowa State College at Ames, where he received the Degree of Bachelor of Science in Mechanical Engineering in 1928.

Mr. Jennings was admitted to the Graduate Student Course of the Westinghouse Electric Corp. in 1928, and completed the normal year's course in seven months.

In 1929 he became attached to the mechanics Division of the Westinghouse Research Laboratories in East Pittsburgh, where he instituted advanced studies in the mechanical properties of welds, welding design, welding applications and welding problems.

In 1936 he was transferred to the Laboratories' Chemical and Metallurgical Dept. and put in charge of all the welding research. In 1943 he was made Section Engineer of the Welding Section and in 1945 promoted to Engineering Manager of the Welding Department which position he now holds.

Charles H. Jennings

In 1937, Mr. Jennings was called to England for three months as consultant welding engineer for the English Electric Co. He has also conducted a course in welding metallurgy at the Carnegie Institute of Technology, prepared a training course for welding operators for the Pittsburgh Board of Education and served as part-time staff member of the N.D.R.C. War Metallurgy Division during 1942. He is the author of more than thirty articles on welding and two books, *How to Weld 29 Metals* and *50 Lessons in Arc Welding*.

In 1939, Mr. Jennings was awarded the Westinghouse Silver "W" and Order of Merit for distinguished service in welding research and application. Mr. Jennings has been active in the AMERICAN WELDING SOCIETY for the past twenty years and has held the offices of Chairman Pittsburgh Section, District Vice-President, Director at large and Director Niagara Frontier Section. He was Chairman of the Technical Activities Committee and a member of seven other committees. He has served on six other committees, assisted in the preparation of several chapters for the 1938 and 1942 editions of the *Welding Handbook*, served as a member of the 1950 Handbook Committee and lectured before thirty-eight sections of the SOCIETY. For the past year he served as 2nd Vice-President of the SOCIETY.

Nominee—2nd Vice-President

FRED L. PLUMMER

Fred L. Plummer was born in 1901. He holds a Bachelor of Arts degree from Ohio University and a Bachelor of Science in Civil Engineering from Case School of Applied Science and a Master of Science degree from the same School. He is a Registered Engineer of the states of Ohio and New York. Mr. Plummer has written two books; one, on *Statically Indeterminate Structures* and the other on *Soil Mechanics and Foundations*. He is author of more than thirty articles published in various technical journals of which two on "Pressure Vessels" were published in THE WELDING JOURNAL and *The Oil and Gas Journal*.

Fred L. Plummer

Mr. Plummer was an Instructor and Associate Professor at Case for fourteen years from 1923 to 1937, teaching such subjects as Mathematics, Civil Engineering and Structural Engineering. He was a Lecturer during this period at Cleveland School of Architecture. He also lectured at John Huntington Polytechnic Institute.

In 1928, while on leave from Case, he was in charge of the structural analysis and design of the world's largest Airship Dock for Goodyear Zeppelin Corp. at Akron, Ohio, in association with Wilbur Watson & Associates, Consulting Engineers and Architects. He was also in charge of design of a seven million dollar steel bridge, being associated with Wilbur J. Watson and F. R. Walker.

During his stay with Case he was also consultant for a number of companies, such as the Truscon Steel Co., Republic Steel Co., Dow Chemical Co., U. S. Engineers Corps and others. From 1937 to 1940 Mr. Plummer was Chief Design Engineer of the Main Avenue Bridge Projects, Cleveland, Ohio. The project included the main bridge structure about one mile long with complicated approach structures. It was necessary to partially wreck and remodel many buildings, move and reconstruct many sewer and utility lines. The complete project cost about eight million dollars.

Since 1940 to date Mr. Plummer has been Chief Engineer and now Director of Engineering of the Hammond Iron Works, Warren, Pa. The company fabricates and constructs all types of shop- and field-erected steel plate structures and vessels used by the chemical, rubber and petroleum industries.

Mr. Plummer is a member of the following scientific and engineering societies: American Society of Mechanical Engi-

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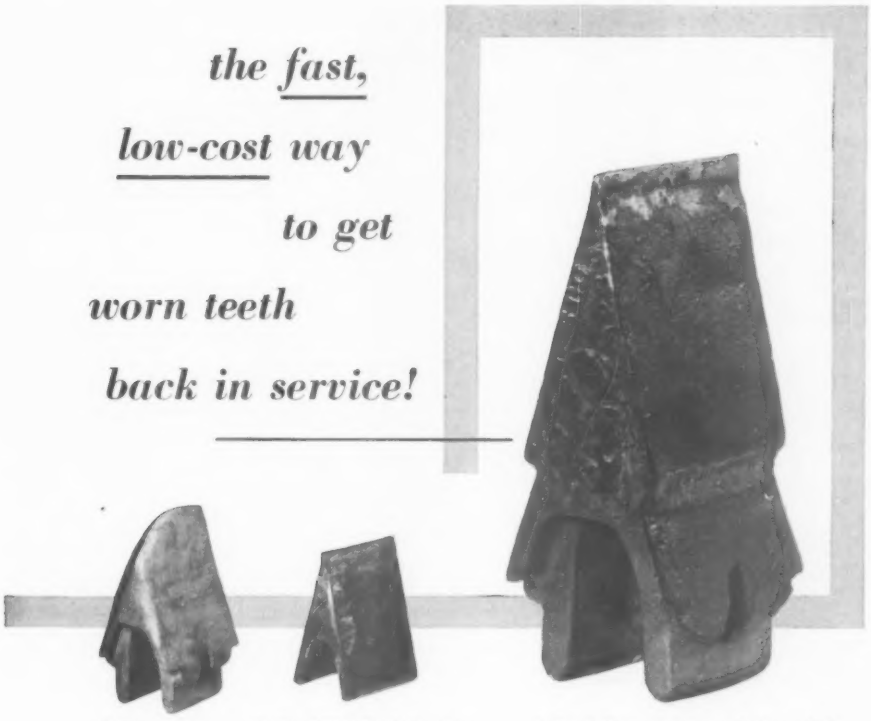

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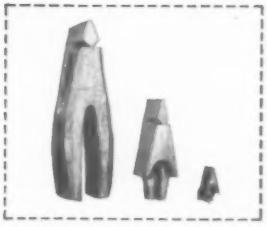

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neers, American Society of Civil Engineers, American Society for Testing Materials, American Petroleum Institute, American Concrete Institute, AMERICAN WELDING SOCIETY, Highway Research Board, American Society for Engineering Education, Cleveland Engineering Society, Welding Research Council, Society of Sigma Xi, Tau Beta Pi and Phi Beta Kappa.

In connection with the AMERICAN WELDING SOCIETY he was Director from 1941 to 1944; Chairman of the Cleveland Section from 1938 to 1941. He has served on the Committee on Awards and on the Handbook Committee. He is also a member of the Pressure Vessel Research Committee of the Welding Research Council.

Nominee—Treasurer

R. S. DONALD

Russell S. Donald has been renominated for a second term as treasurer of the SOCIETY. Mr. Donald is a man of extensive business experience. He was born on Feb. 6, 1891. He started his business career as a tool maker and designer. He joined the Thomson Electric Welder Co. in 1909 and has been with the company ever since. He now holds the position of sales engineer.

In 1933 he organized the Electroloy Co. for the manufacture and supply of resistance-welding electrodes. He is president of the Conlon Manufacturing Co., Bridgeport, Conn. This company specializes in the manufacture of rubber shoe machinery and general machine work. He is also affiliated with several other enterprises.

Russell S. Donald

Russell Donald has been active in the AMERICAN WELDING SOCIETY over a long period. He has served as a member of the technical committees interested in resistance welding and has been a member of the National Program Committee for many years. He has also served on the Board of Directors and on the Finance Committee. He is now serving as treasurer for a three-year period.

Nominee—Vice-President, District No. 2

A. G. BISSELL

Mr. Bissell is Civilian Head of the Welding and Metals Branch of the Bureau of Ships, Navy Department, Washington, D. C.

He is a native of New York State, receiving his early education in the public schools of LeRoy, New York. He graduated from the Tacoma, Washington

A. G. Bissell

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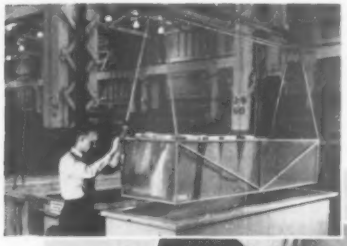

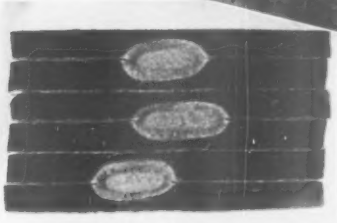

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High School and attended the University of Washington at Seattle, from which he graduated with the degree of B.S. in Chemical Engineering. He was elected to the Phi Lambda Upsilon, National Honorary Chemical Society at the University of Washington. His thesis "The Use of Arc Welding in Steel Ship Construction" in 1920 is believed to be the first thesis on welding to be accepted by a University for an advanced degree, that of Chemical Engineer.

Between 1918 and 1921 Mr. Bissell did early development work in applying arc welding to Naval ship construction at the Puget Sound Navy Yard, and in 1923 he became General Engineer on welding with Westinghouse at East Pittsburgh. He was actively associated with the design and erection of the first all-welded through plate girder railroad bridge at Turtle Creek, Pa. After leaving Westinghouse, he spent several years in consulting work in Welding Engineering in Seattle, Portland and Los Angeles.

Since 1936 Mr. Bissell has been connected with the Navy Department. He has been a member of the AMERICAN WELDING SOCIETY since 1923, has served on the National Board of Directors and was the first Chairman of the Washington Section. He was closely connected with the development of armor welding by the Navy before World War II, and was a member of the subboard of the Board convened by the Secretary of the Navy to investigate the design and construction of welded steel merchant vessels. He is a member of the Welding Committee of the American Bureau of Shipping.

In 1942 he was a recipient of the Lincoln Gold Medal, in 1946 received the Meritorious Civilian Award from the Bureau of Ships and in 1949 was awarded the Samuel Wylie Miller Memorial Medal of the AMERICAN WELDING SOCIETY.

Nominee—Director

C. B. VOLDRICH

C. B. Voldrich is in charge of welding research at Battelle Memorial Institute, Columbus, Ohio. In this position, which he has held for the past nine years, he has directed research in many branches of welding such as weldability of steels, welding process development, welding electrode development, flash welding, pressure welding, and welding of aluminum alloys and special metals and alloys. He is an active worker on various technical committees concerned with improvements in welding techniques and materials. He currently serves on several committes and subcommittes of the AMERICAN WELDING SOCIETY and the American Standards Association. In the past ten years, he has been the author or co-author of numerous research papers on welding published in THE WELDING JOURNAL and other technical periodicals, and has given technical talks on various welding subjects at meetings of many sections of the AMERICAN WELDING SOCIETY.

Mr. Voldrich is a graduate of Purdue University, from which he holds the degree of Bachelor of Science in Civil Engineering, and from the University of Wisconsin,

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BUILT-IN REMOTE CONTROL Dial-lectric feature gives full arc-control at the work . . . saves operator's time . . . saves floor space for production.

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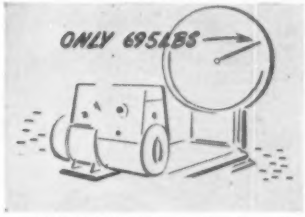

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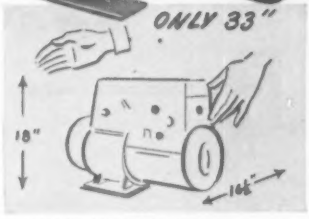

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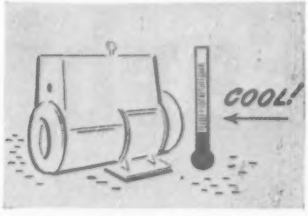

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C. B. Voldrich

where he received the degree of Master of Science (Structural Engineering). Before joining the Battelle staff in 1941, he was associated successively with the A. O. Smith Corp., the metallurgical research staff of the University of Wisconsin, the Portland Cement Assn. and the Bureau of Ships. He is a member of the AMERICAN WELDING SOCIETY, American Institute of Mining and Metallurgical Engineers, and Sigma Xi and Tau Beta Pi honor societies, and is a registered professional engineer in the State of Ohio.

Nominees Nominating Committee

DISTRICT NO. 2, LOU AMES

Mr. Lou Ames received his training in welding in the U. S. Navy in 1920 at the Aviation Mechanics School at Great Lakes, Ill. After completion of his enlistment he worked in various parts of the country and spent 18 months in South and Central America on construction projects. He taught welding in 1927 at the Flint Institute of Technology, and later ran a job shop for several years in Philadelphia. He attended Pittsburgh Academy, Temple University, Carnegie Tech. and took a course in Engineering through ICS.

In 1934 Mr. Ames was employed by Airco and has served in various capacities, including Supervisor of Technical Sales in Pittsburgh and is now Technical Sales Representative for the Air Reduction Sales Co., in the Central Region of Pennsylvania.

Editor's Note: Other Biographies of nominees selected by the nominating committee will be published in the July issue of THE WELDING JOURNAL.

Lou Ames

RWMA Announces the Five-Man Jury of Award for 1949–50

The Resistance Welder Manufacturers' Association has announced that the Five-Man Jury of Award for their 1949–50 prize contest will consist of: W. E. Crawford, A. O. Smith Corp., Milwaukee, Wis., *Chairman*, W. E. Smith, Midland Steel Products Co., Detroit, Mich., R. M. Wilson, The International Nickel Co., New York, N. Y., B. L. Wise, National Electric Welding Machine Co., Bay City, Mich., and Professor R. A. Wyant, Department of Metallurgical Engineering, Rensselaer Polytechnic Institute, Troy, N. Y.

The Jury of Award will judge the various papers which are submitted in the RWMA Prize Contest on Resistance Welding Design, Application and Research. Prizes totaling $2250 will be distributed.

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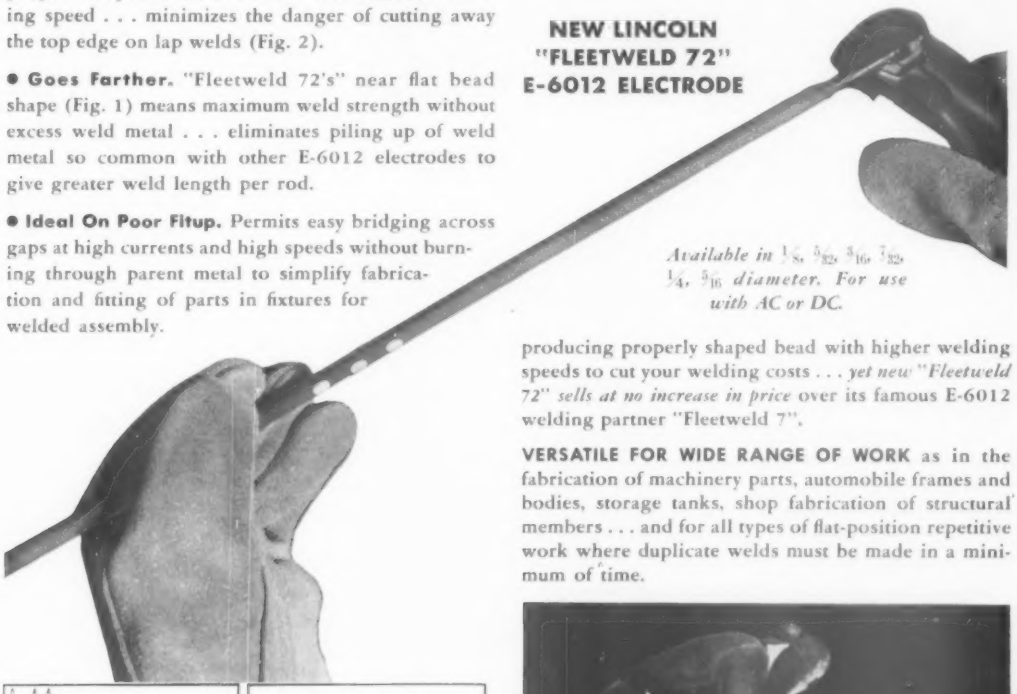

Available in $\frac{1}{8}$, $\frac{5}{32}$, $\frac{3}{16}$, $\frac{7}{32}$, $\frac{1}{4}$, $\frac{5}{16}$ *diameter. For use with AC or DC.*

VERSATILE FOR WIDE RANGE OF WORK as in the fabrication of machinery parts, automobile frames and bodies, storage tanks, shop fabrication of structural members . . . and for all types of flat-position repetitive work where duplicate welds must be made in a minimum of time.

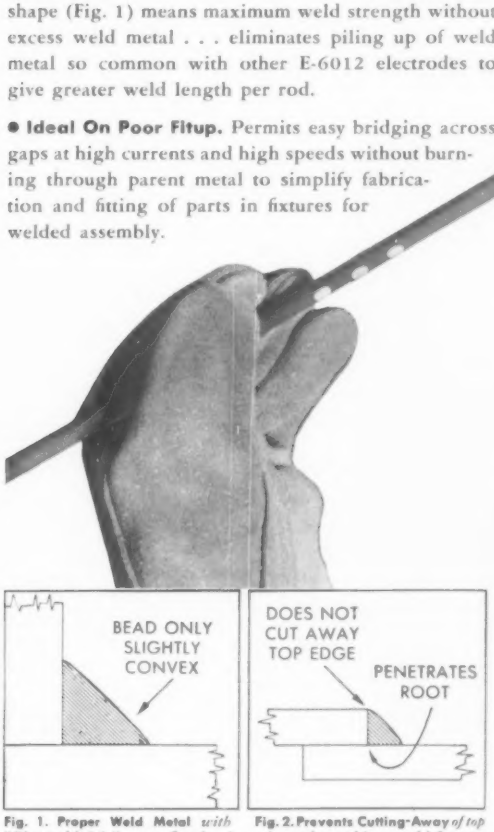

Fig. 1. Proper Weld Metal *with "Fleetweld 72's" near flat bead means greater "mileage" from each electrode.*

Fig. 2. Prevents Cutting-Away *of top edge on lap welds . . . weld flows up to catch top edge without sacrifice in speed. Prevents piling up of metal.*

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Write for free Procedure Bulletin

THE LINCOLN ELECTRIC COMPANY

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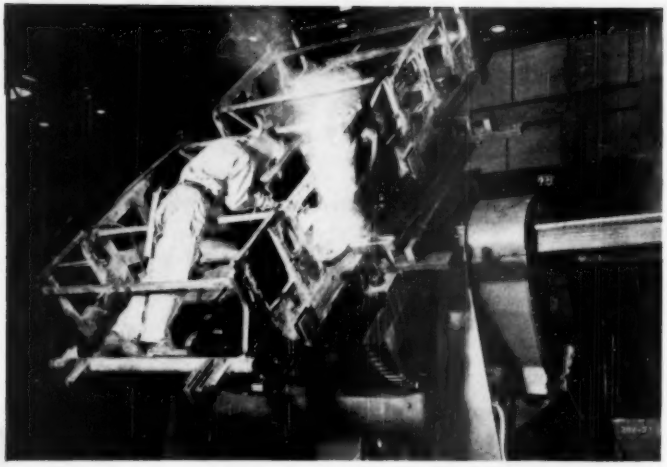

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You pay your welders for welding . . . so the time it takes them to *position* the work—or themselves—is *lost* welding time.

But a Worthington-Ransome Positioner quickly tilts and rotates the work for practically *continuous* welding—always in the efficient *downhand* position that permits using heavier electrodes for *quicker, neater, better* welds.

Mass production or job welding . . . small pieces or "crane" work . . . automatic or manual welding—Worthington-Ransome Positioners quickly *pay* for themselves with increased production, lowered labor costs—up to 50%.

Capacities from 100 lb. to 20 tons.

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WORTHINGTON PUMP AND MACHINERY CORPORATION

Welding and Assembly Positioning Equipment Division

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50% PRODUCTION UP LABOR COSTS DOWN

Welding Positioners Turning Rolls

Worthington Pump and Machinery Corp.
Dunellen, N. J.

Please send Bulletin 210C on Worthington-Ransome Welding Positioners.

NAME .....

COMPANY .....

ADDRESS .....

A prize of $750 will be awarded for the best paper from an Industrial Source, Consulting Engineer or Government or Private Laboratory on the subject of Resistance Welding. This paper should include the economic importance of the accomplishments described. As second prize, $500 will be presented in this classification; and, $250 will be given to the third place winner.

For a paper emanating from a university or educational source, which the jury feels has made the greatest contribution to the advancement and use of Resistance Welding, a prize of $300 will be presented. $200 will be awarded to the second best paper in this classification.

A special prize of $250 is available to an undergraduate who presents the best paper on Resistance Welding.

The contest, which closes July 31, 1950, is open to all from the United States, its possessions and Canada.

Papers should be addressed to the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. All papers to be typewritten, double spaced and on one side only of blank white paper. Photographs, charts, graphs, etc., may be either attached or detached with identifying numbers or captions.

Board of Directors Meeting

A meeting of the Board of Directors of the AMERICAN WELDING SOCIETY was held in the Hotel Statler, New York, N. Y., Room 129, at 10:00 A.M. on Tuesday, March 21, 1950, with the following in attendance:

Members: O. B. J. Fraser, *Chairman*, D. Arnott, L. C. Bibber, R. S. Donald, H. O. Hill, J. H. Humberstone, T. M. Jackson, C. H. Jennings, C. I. MacGuffie, A. J. Moses, H. W. Pierce and F. L. Plummer.

By Invitation: D. Joseph, A.W.S. Auditor.

A.W.S. Staff: J. G. Magrath and F. J. Mooney.

Acceptance of Minutes of March 15, 1950 Finance Committee Meeting

The minutes of the March 15, 1950 Finance Committee Meeting as submitted at this meeting were accepted and recommendations of the Finance Committee met with the approval of the Board of Directors. These recommendations consisted of:

(1) Extending the period for which delinquent members are to be carried on the rolls of the SOCIETY for the 1949–50 membership year, from March 31st to April 30th.

(2) The SOCIETY'S Secretary to send out a final statement to all delinquent members. This statement to have the words "FINAL NOTICE" indicated thereon and be in red print or rubber stamped in red so as to be as effective as possible.

(3) Finance Committee favored sending formal statements to the A.W.S. delinquent members in place of past procedure and for the Assistant Treasurer to secure prices thereon and to report to

the Finance Committee the cost, and to put into practice, in the future, this method of invoicing delinquent members.

1951 Adams Lecturer

After due consideration of the 1951 Adams Lecturer candidates, proposed by the Committee on Awards, twelve (12) ballots were cast which resulted in the unanimous selection of Mr. J. J. Chyle as Lecturer.

A.W.S. Past-President's Award

The Board of Directors approved of granting life membership, an appropriate certificate and a suitable pin to A.W.S. Past-Presidents. Further, it was directed that the matter of life membership in the Society for A.W.S. Past-Presidents be referred to the Constitution and By-Laws committee for necessary inclusion in the Society's By-Laws and for the Constitution and By-Laws Committee to report its recommendation of proposed change in the Society's By-Laws to the Board of Directors at their next meeting to be held in May 1950.

It was recommended that Article IV, Section 4 entitled "Cancelled Dues" be rewritten to comprehend life membership for A.W.S. Past-Presidents.

Approval of District Boundary Changes

The Board of Directors voted favorably on the transfer of New York and New Jersey Sections from District No. 1 to District No. 2, to become effective Sept. 1, 1950.

Junior Membership Classification

After reviewing the matter, the Board of Directors were in agreement with the Executive Committee that the Society should not establish an additional membership classification but that the Society should encourage vocational students to subscribe to The Welding Journal or enroll as Associate Members.

Securing of Convention Headquarters Two Years in Advance

At a meeting of the Executive Committee on Nov. 3, 1949 the Executive Committee directed that the National Convention Committee instruct the Secretary to make necessary arrangements for Convention Headquarters for the 1951 Annual Meeting, which Meeting is scheduled to take place in Detroit, Mich.

The Board of Directors ordered that in the future the Society's Secretary is to consult with the section Officers of the Section located in the city where the Convention will take place. After consultation with the Section Officers, the Secretary is to then proceed to make necessary arrangements for headquarters' hotel and overflow hotels in that city.

A.W.S. Registration Fee at the 1950 Annual Meeting

At an Executive Committee meeting of the Society on Nov. 3, 1949, the Committee voted favorably to charge a registration fee at the 1950 Annual Meeting in the order of $1.00 to A.W.S. members and $2.00 to nonmembers.

The Board of Directors felt that the Society should try out the practice of a registration fee for this year. It was observed by certain members: (*a*) the noncharge of registration fee by A.S.M. should have no effect on A.W.S. attendance; (*b*) that the income from exhibit space and sales at the National Meeting would not defray the expense of the National Meeting this year and that other income was necessary.

Recommendations of the Technical Activities Committee

1. The T.A.C. recommended to the Board of Directors that the Tentative Recommended Practices for Inspecting, Repairing and Repainting Elevated Steel Water Storage Tanks, Standpipes and Reservoirs, be approved for issuance as joint standards of the American Welding Society and the American Water Works Association.

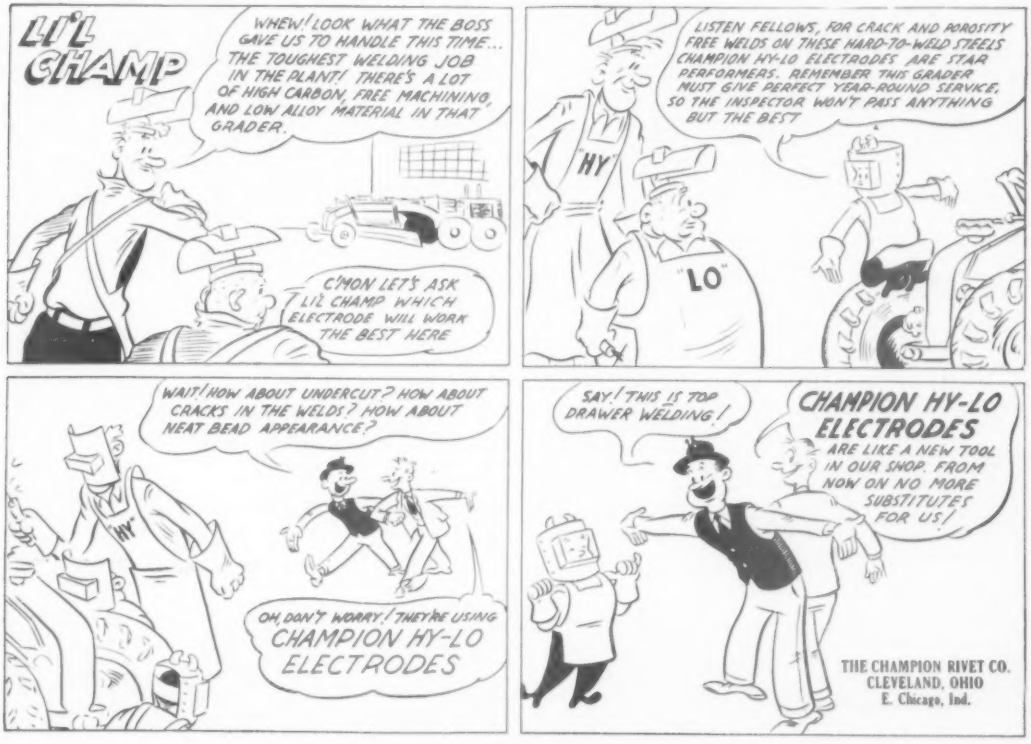
The Board of Directors so approved.

2. The T.A.C. recommended to the Board of Directors that J. J. Chyle and C. B. Voldrich be appointed as American Welding Society representatives on A.P.I.-A.G.A. Committee on Field Welding of Natural Gas and Oil Pipelines.

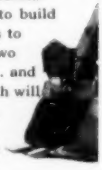
The Board of Directors so approved.

In addition the Board of Directors are of the opinion that this activity should be more closely identified with A.W.S.

3. The T.A.C. recommended to the Board of Directors that the Recommended Practices for Salvaging Automotive Gray Iron Castings by Welding be approved


LI'L CHAMP
WHEW! LOOK WHAT THE BOSS GAVE US TO HANDLE THIS TIME... THE TOUGHEST WELDING JOB IN THE PLANT! THERE'S A LOT OF HIGH CARBON, FREE MACHINING, AND LOW ALLOY MATERIAL IN THAT GRADER.
C'MON LET'S ASK LIL CHAMP WHICH ELECTRODE WILL WORK THE BEST HERE
LISTEN FELLOWS, FOR CRACK AND POROSITY FREE WELDS ON THESE HARD-TO-WELD STEELS CHAMPION HY-LO ELECTRODES ARE STAR PERFORMERS. REMEMBER THIS GRADER MUST GIVE PERFECT YEAR-ROUND SERVICE, SO THE INSPECTOR WON'T PASS ANYTHING BUT THE BEST
HY
LO
WAIT! HOW ABOUT UNDERCUT? HOW ABOUT CRACKS IN THE WELDS? HOW ABOUT NEAT BEAD APPEARANCE?
OH, DON'T WORRY! THEY'RE USING CHAMPION HY-LO ELECTRODES
SAY! THIS IS TOP DRAWER WELDING!
CHAMPION HY-LO ELECTRODES
ARE LIKE A NEW TOOL IN OUR SHOP. FROM NOW ON NO MORE SUBSTITUTES FOR US!
THE CHAMPION RIVET CO.
CLEVELAND, OHIO
E. Chicago, Ind.

ANNOUNCING another
Made-To-Fit-Your-Job
ELECTRODE BY
Low Temperature
EUTECTIC
WELDING ALLOYS
EUTECHROM 10
FOR YOUR
HARD OVERLAY JOBS
demanding resistance to
impact and abrasion



Here's an example: For bucket teeth tips, working in hard shale formations, use EutecTrode 680 to build up the manganese steel tips to shape. Then overlay with two layers of EuteChrom 10 . . . and you will have a surface which will outlive any other overlay on the market. No ill effects on the parent metal, because it's a "low heat" operation.

DEMAND THESE RESULTS
on *YOUR* OVERLAY JOBS!

For any kind of overlay job . . . especially if it demands resistance to impact and abrasion, specify EuteChrom 10—Eutectic's new easy-to-use electrode for hardest overlay. This electrode develops a Rockwell "C" hardness between 63 and 68—roughly the equivalent of Brinell 672 to 740 . . . about as hard as a weld can be! Use EutecTrode 680 first, as the ideal cushion material—then apply EuteChrom 10, *both* at low heat.

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Address_____
City_____ State_____

for publication as a Tentative Standard of the SOCIETY.

The Board of Directors so approved.

C. H. Jennings reported that the Technical Activities Committee elected C. D. Evans and J. Lyell Wilson, Chairman and Vice-Chairman, respectively, for a three (3) year term ending September 1952.

The Chairman of T.A.C. appointed the personnel of its Executive Subcommittee to consist of C. D. Evans, *Chairman;* S. A. Greenberg, *Secretary;* J. Lyell Wilson, R. W. Clark, J. J. Chyle, C. H. Jennings and J. Heuschkel, which Subcommittee is to act in the interval between regular meetings of the Technical Activities Committee as is deemed necessary.

Mr. Jennings reported that as a result of action by the Board of Directors at its meeting on Sept. 22, 1949, the Technical Activities Committee has taken the necessary steps to include soft soldering within the scope of the technical activities of the SOCIETY.

Decision Regarding A.W.S. Representative on A.S.A. Sectional Committee Z15-Standardization of Graphics

The Chairman reported that invitation has been received by the SOCIETY to appoint a representative on the A.S.A. Sectional Committee Z15-Standardization of Graphics.

The Board of Directors voted to decline invitation extended by the A.S.A. Sectional Committee Z15 and for the Secretary to inform this Committee that the A.W.S. will adhere to the standards as set. Also, the Board of Directors requested that the JOURNAL Editor shall ask authors of papers submitted for JOURNAL publication to conform with A.S.A. standards.

Membership Reinstatement Charge, Initiation Fee and Membership Delinquency Procedure

The Board of Directors voted favorably on recommendations of the Executive Committee in the order of:

1. No reinstatement charge should be instituted.
2. No initiation fee should be established.
3. Continue to send delinquent members *Journal* during first two (2) months of delinquency.

World Metallurgical Congress

The Secretary reported that W. H. Eisenman, Secretary of the American Society for Metals, and Director of the National Metal Exposition and Congress, presented a proposed plan for a World Metallurgical Congress to Paul G. Hoffman, Administrator of the Economic Cooperation Administration, in Washington, D. C. The proposal comprehends the conductance of a World Metallurgical Congress simultaneously with the Annual Metal Exposition and Congress scheduled for convention in Chicago, Ill., Oct. 21–27, 1950. An outline of Mr. Eisenman's plan was submitted to the Board of Directors and was reviewed by them.

In the opinion of the greater number of the attending Board Members, it was felt that A.W.S. should cooperate to the extent of extending a cordial invitation to the foreign visitors to the World Metallurgical Congress who are guests of E.C.A., to participate in discussion at our Annual Meeting public meetings. They felt that benefits could ensue to all concerned as a result of the proposed activity and that the opportunity for exchange of information at technical level on the subject of Welding Metallurgy and Engineering would be welcomed by our SOCIETY. They stressed that we should not be responsible for other activities of the foreign guests nor responsible for arranging for plant visits or other tours.

Resolution of Appreciation to Editor and Assistant Editor of the Third Edition of the Welding Handbook, Chairman and Members of the Welding Handbook Committee

The Board of Directors upon motion, duly seconded, directed that resolution of appreciation in the order following, as formulated by Messrs. Pierce and Hill, be spread on the minutes of this meeting and transmitted to the Editor and Assistant Editor of the third edition of the *Welding Handbook;* Chairman and Members of the *Welding Handbook* Committee:

"The Board of Directors of the AMERICAN WELDING SOCIETY, at the regular meeting held in New York on March 21, 1950, unanimously passed a motion to express their approval of the 3rd Edition of the *Welding Handbook* and to congratulate those who contributed so much to its success. The Board believes that this outstanding and authoritative treatise, covering all phases of welding, will do much to promote the art and science of welding and to enhance the prestige of the AMERICAN WELDING SOCIETY.

"This volume of work and the unselfish service demanded of those who worked toward the consummation of this project is fully appreciated. The Board of Directors therefore takes this opportunity to extend its hearty thanks to you for the important part you performed as ———."

(Chairman, *Handbook* Committee)
(Member, *Handbook* Committee)
(Editor, *Handbook*)
(Asst. Editor, *Handbook*)

Amendment to Provide for an Advisory Committee of A.W.S. Past-Presidents

Upon motion, duly seconded, the Board of Directors approved of the following wording, as submitted by the Constitution and By-Laws Committee, for the scope and power to be assigned the Advisory Committee of A.W.S. Past-Presidents:

"Renumber Section 20 of Article XII to read Section 21. Renumber present Section 21 to 22 and present Section 22 to 23. Add new Section 20 as follows:

ARTICLE XII, Section 20. Advisory Committee of A.W.S. Past-Presidents. An Advisory Committee consisting of all living past-presidents of the SOCIETY. Each president of the SOCIETY at the termination of his term of office shall automatically become a life member of this committee. At the end of each fiscal year the committee shall elect from its membership a chairman who will serve for one year. This Committee shall, when

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... **BUT** they've been "given the works" by many large fabricators of stainless steel equipment—on the job. And, from all reports, they're the most all 'round satisfactory electrodes PAGE ever developed for any kind of weld on any type of stainless steel. And PAGE has been making stainless steel electrodes since the early development of stainless.

Ask your Page distributor about these new, improved Stainless Steel Electrodes

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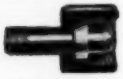
In these days when cost has so much to do with profit, check with BURDOX first on your welding, cutting, or safety equipment. Feature for feature, every one of the hundreds of items in the BURDOX line gives you more service . . . yet costs you less for the same quality. For greatest savings—Best Buy BURDOX! Write for literature today!

Trip-L-Flint Lighters



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If it's for Welding or Cutting . . . we have it!

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called upon, act in an advisory capacity to the Board of Directors and other official SOCIETY committees and shall perform other duties which may from time to time be assigned by the Board of Directors."

Appointment of Special Committee to Study Advisability of the Establishment of a Separate Committee for the Handling of Sales of Books

Previous action of the Board of Directors authorized President Fraser to appoint a three (3) man study committee to render report to the Board as to the advisability of the establishment of a separate committee for the handling of sales of books, pamphlets, educational lectures, etc., published by the SOCIETY.

The purpose of this separate committee would be to study the demand for such material, the availability of authors or authors or authoritative persons for compiling text, the volume in which it should be produced, the list pricing and the proper plan for distribution.

President Fraser at this meeting asked for suggestions from the table for possible candidates to serve on this study Committee. Several were named and the following gentlemen were appointed in the order of T. B. Jefferson, *Chairman;* P. W. Swain and J. Haydock. All of these men have considerable experience in the publishing business, which also have book and other publication subsidiaries.

D. Joseph, A.W.S. Auditor, and E. Holloway, A.W.S. Attorney, are to be invited to attend all meetings of this group.

Membership Status Report of Six (6) Month Period Ended Feb. 28, 1950

President Fraser reported that for the six (6) month period Sept. 1, 1949–Feb. 28, 1950, the SOCIETY reported a gain of 838 members as against a loss of 435 members, resulting in a net gain of 403 members. The total A.W.S. Membership as of Feb. 28, 1950 was 7594. During the first twenty (20) days of March, the SOCIETY enrolled 62 new members and 46 delinquent members remitted payment of dues.

A.W.S. Booth at 1950 Annual Meeting

The Secretary reported that the National Metal Congress and Exposition will furnish gratis, upon request, a booth at the 1950 Metals Show. The Metal Congress and Exposition will, without charge, equip the booth with furniture but will not supply backdrop material. It will be necessary that the booth be manned by A.W.S. personnel.

The Secretary observed that the Booth will have considerable publicity value and that a couple of companies have already offered their services to furnish backdrop material. A.W.S. Sections can be approached to furnish personnel to man the booth.

In view of the benefits that the SOCIETY can possibly accrue from having a booth at the 1950 Metals Show, the Board Members were in favor of requesting a booth from the National Metal Congress and Exposition, for A.W.S.' disposal.

TWECOLUGS
FOR WELDING CABLES

New copper solder type TWECOLUGS are especially designed for making welding connections. They have large diameter stud holes with ample wing nut clearance. Four sizes for cables 6 through 4/0.

TWECO "LUG-SET"

Block and Punch for attaching lugs to cables without using solder.

The punch impacts the lug barrel for a quick connection with maximum strength and conductivity. All you need is a hammer.

TOP AND BOTTOM VIEW OF LUGS ATTACHED

TWECOLUGS—mechanical type, are available for attaching to cable with a wrench.

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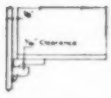
PRODUCTS COMPANY WICHITA KANSAS

A.W.S. Annual Dinner

After discussing the pros and cons of holding an Annual Dinner in which the SOCIETY would be financially responsible for its success or failure, the Board of Directors, upon motion, duly seconded, recommended to the Convention Committee that it give consideration to: (1) scheduling an Annual Dinner—financial responsibility would rest with the National Society; (2) local committee to make arrangements for this dinner and (3) dinner to take place on Wednesday evening.



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Saze System Welded Connection Units
for welded assembly

Saze Units place in position and securely hold together structural parts to be welded.

As used in many welded structures they *eliminate all hole punching* producing an economical, rigid, safe and quickly erected structural frame.

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No. 16 Silver Solder Paste Flux

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NEWS OF THE INDUSTRY

A.S.T.M. Specifications for Steel Piping Materials

This latest compilation of A.S.T.M. Standards on steel piping materials, as of December 1949, the book having come off press March 1950, includes some 50 widely used specifications. Materials covered include: (1) Pipe used to convey liquids, vapors, and gases at normal and elevated temperatures, (2) Still tubes for refinery service, (3) Heat exchanger and condenser tubes and (4) boiler and superheater tubes. To make the volume more complete there are also included specifications for the following materials used in pipe and related installations: (1) Castings, (2) Forgings, (3) Bolts and (4) Nuts.

There are 16 pipe specifications covering seamless and welded; electric-fusion and electric-resistance-welded and other types, in both carbon and alloy grades. Several specifications cover materials for service at high temperatures including austenitic pipe.

For boiler, superheater and miscellaneous tubes there are 13 standards, including three for stainless tubing, ferritic and austenitic, for general service and for sanitary tubing.

Three standards for seamless steel tubes cover applications in refineries; and three other heat-exchanger and condenser tube standards apply to seamless and electric-resistance-welded tubing of various grades.

Various classes and grades of carbon and alloy-steel castings, forgings, welding fittings and bolting are included in 13 specifications. Many of the applications are for high temperature and high-pressure service.

The publication is made more complete and usable by the Grain Size Standard E 19 and also by the American Standards covering steel and iron pipe (B 36.10) and the latest stainless steel document (B 36.19).

Copies of this 328-page book, heavy paper cover, can be procured from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $3.00 each.

Career in Metallurgy

Making use of radio programming techniques, the American Society for Metals has just completed a thirty-minute recording of "Tour Career in Metallurgy," complete with the attention getting background of authentic sound effects and dialog which is largely responsible for the interest in, and growth of Radio.

Produced as one of the projects of the Society's Advisory Committee on Metallurgical Education, the recording takes the young science student through a half-hour of swift moving and dramatic series of facts, from the ancient hammering-out of metal forms to the sound of a supersonic jet plane.

Details available from the American Society for Metals, 7301 Euclid Ave., Cleveland 3, Ohio.

New General Offices for Metal & Thermit Corporation

After 35 years at 120 Broadway, in downtown New York, Metal & Thermit Corp. is moving its general offices to the midtown area. The company's address, as of May 1st, will be 100 E. 42nd St., New York 17, N. Y.

Mobile Machine Shop for Repairing Farm Machinery in Turkey

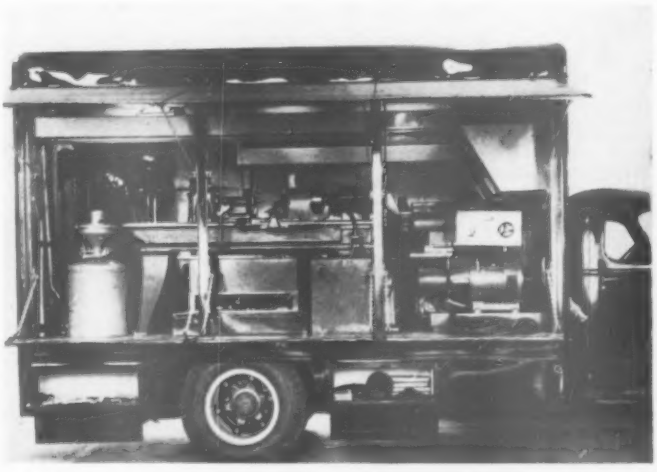
United States farmers, especially during and since the war, do much of their own repair work with an arc welder and other tools. Apparently not so in Turkey. The Turkish government recently purchased from the Davey Compressor Co. in Kent, Ohio, mobile machine shops to move about the country repairing farm machinery. Farm machinery is considered a national asset in Turkey which the government cannot afford to let deteriorate.

The shops are 8 ft. wide, 14 ft. long and 8 ft. high. For basic power sources they have a 300 amp. welder made by The Lincoln Electric Co., Cleveland, Ohio, a 60 cu. ft. air compressor and a 12 kw. a.-c. generator. These power units operate a 14½-in. lathe, a 1-in. capacity drill press, grinder and other electric and air-operated hand tools. The shop also has oxyacetylene equipment, work bench, arbor press, forge, mechanic's tools, blacksmith's tools, plumber's tools and other small items.

Airco Dealers to Carry "Easy-Flo 45"

The new, convenient 5-oz. packets of Easy-Flo 45, a silver alloy for brazing ferrous, nonferrous and dissimilar metals, announced recently by Handy & Harman, has been added to the oxyacetylene welding line of the more than 800 Air Reduction authorized dealers, it was disclosed today. The newly packaged product will also be sold through Airco's regular sales offices. The new Easy-Flo packets contain a 5-oz. coil of $\frac{1}{16}$-in. wire (approximately 330 lineal in.), instructions for use and a folder giving complete details about the product.

According to the manufacturer, this new silver brazing "package" should find acceptance by repair and maintenance crews, in small shops and in shops doing experimental work.



Mobile Machine Shop

More Power to America

THE General Electric Co. recently unveiled its More Power to America Special, the biggest electrical display kit ever built.

Almost a quarter-mile long, the 10-car exhibit train represents the first attempt to display, in one series of related exhibits, the complete range of products for the production, distribution and industrial utilization of electric power.

Believed to be unique in industrial marketing history, the silver streamliner is filled with exhibits of more than 2000 of the most modern electric products, systems and techniques.

"The Special," launched on the rails by the company's Apparatus Department, is in New York on the first lap of a nation-wide tour. It will visit approximatley 150 key industrial centers during 1950 and 1951.

At each stop the train will be inspected by invited representatives of electric utilities, the manufacturing and transportation industries, the armed services, the federal government and municipalities.

The train will not be open to the general public during its tour, according to G-E spokesmen. They explained that the exhibits abroad the train have been designed specifically to interest those who produce electric power and those who put it to work in industry and the community.

Exhibits in the "Special" are grouped in 11 major sections: Power Generation, Transmission and Distribution; Drives and Controls; Materials Handling; Welding; Industrial Heating; Renewal Parts; Industrial Lighting; Components for Industry; Measurements; Civic Improvement and National Security.

The train and its objectives were described in detail by company executives at a luncheon for several hundred representatives of the business and daily press in the Hotel Biltmore. Later, the group inspected the train, spotted on Track 30, Grand Central Station.

Speakers at the luncheon included Henry V. Erben Vice-President and General Manager of the Apparatus Department; Chester H. Lang, Vice-President in charge of Apparatus sales; J. Stanford Smith, Manager of the Apparatus Department's Advertising and Sales Promotion Divisions and Clayton P. Fisher, Jr., Manager of the Apparatus Exhibit Train Division. Robert S. Peare, Vice-President in charge of public relations for the company, presided.

Smith, whose divisions were responsible for the production of the entire train project, declared the exhibit train is a means of assuring that 2000 of the company's "finest mid-century ideas . . . shall be put to work for a more productive America."

Warning that the country faces three dangers from within—drift, dullness and lassitude—that could slow its economy, Smith declared that American free enterprise will not let this happen. In this regard, he said, the exhibit train is "American busines at its best—communicating the ideas that give direction, drama and drive to America's productive economy at mid-century."

Fisher, manager of the division responsible for preparation and operation of the exhibit train, explained that many problems had to be solved in installing a display of this kind in a "tunnel 9½ ft. wide and 1000 ft. long." Specifications worked out for the exhibits, he said, took into consideration such factors as size, weight, center of gravity, shock resistance and electric power requirements.

Wherever possible, actual apparatus has been displayed aboard the "Special." Where size and weight limitations have made this impractical, he explained, scale models or other representations have been used.

Fisher emphasized that there is a planned, logical order to the train's exhibits: visitors first see equipment for producting power, then apparatus for transmitting and distributing it, then, finally, the techniques and products for profitably utilizing it.

(Continued on page 526)

Shown here is the welding display section of the More Power To America Special

Included in this section, one of 11 exhibit units aboard the 10-car streamliner, are a complete line of arc-welding equipment and accessories, samples of various welds and resistance-welding control items

The More Power to America Special, the General Electric Apparatus Department's 10-car exhibit streamliner, rounds a bend on the New York Central tracks outside of Schenectady, N. Y.

NEW LITERATURE

Structural Design in Metals

Structural Design in Metals, by Clifford D. Williams, Head Professor of Civil Engineering, University of Florida, and Ernest C. Harris, Chairman, Department of Structural Engineering, Fenn College. First award in the Structural Design Division of the competitive program for modernized textbooks on design sponsored by The James F. Lincoln Arc Welding Foundation.

The authors have attempted in *Structural Design in Metals* to provide the material for a coordinated course of instruction in that subject for students at the level of the Junior year in the average engineering college.

An attempt is made to analyze both welded and riveted details in each phase of work.

Book consists of 596 pages. The Ronald Press Co., New York.

Brittle Fracture in Design

Bulletin No. 5 of the Welding Research Council contains two important articles on a subject which is engaging the attention of all designing and welding engineers concerned with field erected welded structures. The first article is entitled "How Plastic Deformation Influences Design and Forming of Metal Parts," by John R. Low, Jr. of the General Electric Co. This article is an explanation of plastic flow in metals and how application of knowledge gained to date on this subject can be used to advantage in the design and production of metal products. The second article on "Brittle Fracture in Mild Steel," by Dr. J. S. Hoggart is a monograph on the subject covering mechanical and metallurgical aspects in engineering terms. Suggestions are made for reducing the danger to brittle fracture.

Price per copy $1.00. Order through American Welding Society, 33. W. 39th St., New York 18, N. Y.

Flame Hardening Reprint

The availability of a 12-page reprint entitled, "Oxyacetylene Flame Hardening in Commercial Heat Treatment" has been announced by Air Reduction Sales Co., A Division of Air Reduction Co., Inc.

The article, which originally appeared in The Welding Journal is illustrated with 22 photographs, covers the range of materials which may be oxyacetylene flame hardened, outlines the various flame-hardening methods and offers typical applications of the process. Cost and hardness tables are also given.

Copies of this reprint may be obtained without charge by writing the Airco office nearest you or Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y., and asking for Form (ADR-63).

Guide to Hardfacing

The widespread interest of welders, engineers, tool designers, maintenance foremen—in fact, all industrial personnel to whom equipment wear is a problem—has led to the preparation of this new edition of the Mir-O-Col "Welder's Guide to Successful Hard-Facing."

Numerous changes have been made in the text in order to incorporate into the booklet the latest data and instruction about hard-facing procedure, as well as new information about Mir-O-Col Alloy Company's own line of hard-facing metals and their application and uses in industry.

Mir-O-Col Alloy Co., 312 North Ave., 21, Los Angeles, 31, Calif.

Resistance Welding in Mass Production

Resistance Welding in Mass Production by A. J. Hipperson, B.Sc. (Eng.), A. M. Inst. W., and T. Watson, N. Inst. W. Published for "Welding" by Iliffe & Sons Ltd., on March 30, 1950. Size ($8^{3}/_{4}$ x $5^{1}/_{2}$"), 278 pages, illustrated with over 220 photographs and diagrams; and including 22 reference tables. Cloth bound with jacket. Distributed by British Book Centre Inc., 122 E. 55th St., New York 22, N. Y.

Up to about ten years ago knowledge and use of resistance welding was in a most unsatisfactory state; but great advances were made during the war years. It was then realized that resistance welding offered many possibilities in the efficient mass production of fabrications in metal.

At the present time, when the emphasis is on productivity—which involves both the production of large numbers of products and economy in their manufacture—it is in the interests of all metal users to be aware of the fields of resistance-welding applications and to know how to use them to the best advantage.

It is, therefore, metal users in general to whom this book is primarily addressed—in particular it will interest welding and production engineers, designers, and students of welding and engineering production. Particular reference is made to design and production requirements, both from the point of view of the design of component parts for optimum results from welding, and the design of jigs and tools for the correct use of the processes under mass-production conditions.

The ground covered by the book ranges from the first principles of each process to its scientific application in mass production. One of the authors is Chief Development and Liaison Engineer of the British Welding Research Association and the other is a practical works manager: their association in the preparation of the data given has been such as to result in an authoritative combination of theory, and practice on a subject hitherto comparatively neglected.

Contents include: Preface; Selection of the Process; Spot Welding: Applications, Spot Welding Machines, Electrodes for Spot Welding, Jigs and Spot Welding; Projection Welding: Principles, Projection Welding Machines, Projection Welding Electrodes, Jigs and Tools for Projection Welding; Seam Welding: Principles, Seam Welding Equipment; Hot Riveting: Principles and Applications, Electrodes and Jigs for Hot Riveting; Flash and Butt Welding, Principles, Butt and Flash-butt welders, Flash Welding Dies and Fixtures, Control Equipment for Resistance Welders; Recommended machine Settings; Testing and Inspection of Welded Joints; Design, Testing Methods, Resistance Welding Costs; Bibliography and Index.

15 Production Welding Case Histories

New production welding techniques are discussed in an 8-page brochure recently published by the Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y.

Selected from hundreds of documented case histories, the 15 chosen for this brochure cover a wide field of industrial applications in many major industries which use production welding. The brochure examines such problems as finishing costs, scaling, distortion, softening of heat-treated metals, burn through, weld failure from impact, joining of dissimilar metals and others.

The stories on the production welding of steel, aluminum, copper, cast iron, bronze and stainless, show how considerable savings may be effected in the manufacture of refrigeration equipment, electronic devices, machinery, trailers, precision instruments, foundry castings, washing machines and other appliances.

This booklet may be obtained free by writing for Volume 6, No. 7, to the address given above.

Hard-Facing Reprint

A new reprint entitled, "Hard-facing Applications in the Steel Industry," has been announced by Air Reduction Sales Co., a division of Air Reduction Co., Inc.

The article, which originally appeared in The Welding Journal, was written by Airco hard-facing specialist J. J. Barry and covers the topic of hard facing as applied to steel industry problems. Sections are included on types of electrodes, service conditions, typical applications, techniques and methods and economies obtained.

For a free copy of the 8-page, illustrated reprint, write Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y., or the Airco office nearest you.

NEW PRODUCTS

Arc Welders

A new line of industrial arc welders has made its bow in America this past month with the introduction, for the first time in the United States and Canada, of the Elin Arc Welder.

The presentation has been made by the American Elin Corp., a newly formed American company with offices at One Wall St., New York, N. Y. A nation-wide distribution is being established from all key cities.

Their welder is the leadoff in a projected program for distribution here not only of welding equipment but of motors, transformers, switchgear and other general utility items from the highly diversified electrical equipment lines of the Elin Electrical Mfg. Co., Ltd., Vienna, Austria.

The first Elin welder to be presented is their Model RFN 300 D.-C. Arc Welder. This fully N.E.M.A. rated machine is a single operator, motor-driven series excited d.-c. welder rated at 60-375 amp., 1750 rpm. and employing the Cross Field Operating Principle.

Welding Electrodes

Arcos Corp., of Philadelphia, Pa., announces the development of three new additions to their line of low-hydrogen welding electrodes. Known as the Tensilend electrodes, they simplify fabrication by the elimination of preheat in welding low-alloy high-strength steels in the 70,000-, 100,000- and 120,000-psi. tensile strength class.

The electrode called Tensilend 70, developed for welding steels in the 70,000 psi. class, is believed to have the broadest field of application. With its stainless type coating and high-tensile weld deposit, it can be used both for welding low-alloy high-strength steels and also for welding mild steels under highly restrained conditions, high carbon steels and sulphur-bearing free-machining steels. Tensilend, 120, for 120,000 psi. steels, was developed for marine applications, such as welding armor plate and its further possibilities are still being explored.

Because these electrodes will perform satisfactorily without preheat, even in freezing temperatures, they are expected to lower the costs of metal fabrication and to be especially useful in field work.

These low hydrogen electrodes leave a mild steel deposit, but differ from most mild steel electrodes in possessing higher tensile strength, better elongation and better impact strength at both room and freezing temperatures.

By eliminating preheat, they overcome a fabrication problem of cast steel foundries, and without annealing, provide sound, crack-free welds with properties comparable to that of the cast steel after the customary stress relieving heat treatment. Since there is no underbead cracking, sound welds in less time can also be produced by builders of rolling stock, such as railroad cars, trucks, construction and earth moving equipment, who are welding the newer high-strength low-alloy steels to eliminate dead weight.

A special feature is the high temperature baking to drive off moisture, and the packaging which prevents moisture absorption before use. Ten-pound lots are wrapped in moisture-proof paper before being boxed. This is an exclusive feature of Arcos electrodes, and one which has been found, from experience with stainless and other low-alloy electrodes, to be necessary for best performance.

Other basic advantages of this new series of electrodes are:

1. Easy handling. The electrodes have a quiet arc and low spatter loss. The slag is easy to manipulate when molten and easy to remove when cold.

2. Exclusive quality controls give consistent dependable welding performance and reduce rejects.

Write to Arcos Corp. for a bulletin on the ABC's of hydrogen controlled electrodes.

Thermo-Grip Soldering Tool

A new "Standard" 1000-watt economy model Thermo-Grip Soldering Tool is being announced by Ideal Industries, Inc., 1938 Park Ave., Sycamore, Ill., that operates on the resistance heating principle as do all Ideal Thermo-Grip models.

This new low-priced portable unit does the job quicker, safer and easier, eliminating fire hazards and discolored work.

Touching the work with the tool completes the secondary power circuit, and heating begins instantly—there is no preheating, no waiting. It is always ready—yet draws current only when actually in use and in contact with the work.

Electronic Timer

Photoswitch Incorporated of Cambridge, Mass., presents Electronic Timer Series 30 which is recommended for process control and machine timing when long life, repeat cycle operation or precise accuracy is desired. The Timer is recommended to control such automatic equipment as drilling machines, automatic filling machines, photographic printers, spot welders, grinders and honing machines.

The electrical circuit of Photoswitch Series 30 Timer provides for four basic types of timing: Interval, Delayed Action, Automatic Repeat and Programming, as well as many variations of these four fundamental types. The basic circuit has been carefully designed so that it is self-compensating for changes in line voltages.

Welding Gloves

The addition of three new styles of welding gloves to their supply line has been announced by Air Reduction Sales Co., a division of Air Reduction Co., Inc., it was announced recently.

The new gloves are labeled, "A," "B" and "C."

The "A" gloves, most costly of the three, are made of soft, rugged carpincho leather with a wool-lined back for maximum heat resistance. A one-piece leather back, which included fingers and gauntlet, is designed to eliminate exposed seams and to increase the life of the glove, the manufacturer reports. Stitching is of the inseam type, and extra protection is provided by a $\frac{1}{4}$-in. wide leather welt which extends around the thumb seam and across the base of the fingers.

The "B" gloves are a gauntlet type in the medium price range and offer the same construction features as the "A." These gloves have palm, thumb and fingers made of chrome-tanned horsesplit, with No. 1 cowsplit back.

The "C," most economical of the three, offers construction features similar to "B" but has a two-piece lined leather gauntlet. All three gloves are medium-full size.

For information about these gloves and other accessory items, write, for Catalog 13, to the Airco Sales office nearest you or Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Machine Vise

Van Products Co., of Erie, Pa., has recently announced a new Machine Vise combining great accuracy, high power, long stroke and extremely simple design. The unit incorporates no levers, wedges, etc., its great power resulting entirely from the large diameter cylinder. Its accuracy, resulting from careful machine work, can be indefinitely maintained as there are adjustable gibs to easily remove all play which may possibly develop from long, hard use. The moving jaw is so designed that the usual tendency to rise up from the vise bed is prevented by the long arms which extend forward from the lower side of the jaw, providing tremendous leverage against unwanted jaw action. The stroke of the standard model is $1\frac{1}{4}$ in., facilitating the holding of variable size pieces and the use of plain and complicated holding fixtures. A 6-in. stroke is available for special uses such as pressing, shaping, forming, etc. Model 811 has large capacity as the jaws are $8\frac{3}{8}$ in. wide and open to a maximum of 11 in., and the chosen opening is preset by the standard socket head wrench. The jaws close and open quickly without hammer effect, and the speed of both actions is easily adjusted. Complete safety to the operator is built into every model as the safety stop screw positively prevents jaw movement beyond any chosen spot, and the jam nut provided will guarantee this adjustment until changed by the operator.

Electrode Holder

A 500-amp. electrode holder of the blade type, known as the BT-5, taking $^3/_8$-in. electrodes, is now made by Jackson Products, Warren, Mich.

Blade-type spring steel jaws are $^7/_8$ in. wide and grooved to hold rods at four different angles, in either right or left hand. Cables may be brazed, soldered or clamped to the copper alloy cable connector.

Like the recently announced 300-amp. blade-type holder it consists of only few parts, easy to replace. It is well insulated, including the improved Jackson jaw insulators, and is exceptionally cool working.

Precision Torch

The Precision Engineering & Mfg. Co. of Saginaw, Mich., has announced the start of volume production of its recently developed butane-propane gas torch, hereafter to be known by its tradename, the Precision Torch, according to Preston Y. Davis, Company President.

Weighing only 4 lb. fully loaded, yet capable of generating heat up to 2200°, it is believed to be the first torch of its kind on the market. The Torch has no hoses, tanks or moving parts of any kind. It is totally self contained in a cylinder $10^1/_2$ in. high and $2^1/_2$ in. in diameter.

The Torch, designed for light brazing, soft and hard soldering and all other general heating operations (requiring temperatures up to 2200°) can be used in any position without impairing its effectiveness. It can easily be filled by any individual or liquid petroleum gas dealer from a bottled gas tank. One filling gives seven hours of continuous operation at a cost of less than four cents. Pressure is constant until the Torch is completely empty.

Precision Engineering & Mfg. Co., 327 Center St., Saginaw, Mich.

Goggle

A headrest goggle for gas welders, cutters, burners, brazers and furnace men with new, simple means for making it easily adjustable to any head size is announced by American Optical Co., Southbridge, Mass.

The company has adapted the "free-floating" headgear long used on AO welding helmets for use on the goggle. A slight twist of a knob adjusts the goggle to the wearer's head size. The mechanism is enclosed in a fiber tube for insulation and to prevent hair pulling.

The "free-floating" headgear provides perfect balance with no overhanging weight and the goggle may be instantly changed to the "off-guard" position by a flick of the wrist.

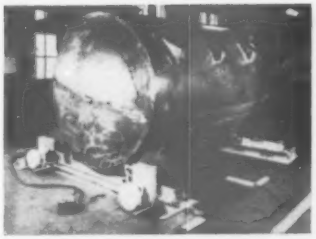
Designed to be worn over eyes or personal glasses, the goggles have well ventilated, indirect side shields to keep out sparks, metal splashes and stray light rays. The new headrest goggle may be obtained with either Noviweld or Noviweld-Didymium lenses in several shades; replaceable cover lenses are provided to protect these more costly filter lenses.

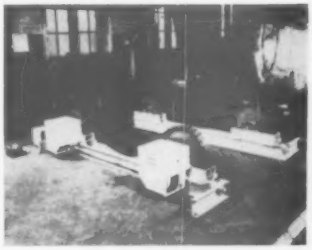
For more complete details ask your nearest AO-Branch for bulletin 8895.

Turning Roll

The "TracTred" was designed for the purpose of cradling light gage tanks that heretofore required that operator to make up a ring or stiffener about that area to be supported on the rolls. Conventionally a light gage tank will collapse on the wheels and, of course, could not be automatically welded or rotated accurately because of this condition.

Other features of the "TracTred" are that it affords infinitely variable speeds from zero to 100 in. per minute. It can be adjusted quickly for various size tanks with a screw-jack that travels only 4 in. for tanks from 5 to 10 ft. in diameter.





These turning rolls are presently designed for 10,000 lb. capacity with a powered set and an idler set (these two minimum requirements) although an extra idler set can be used to increase the capacity to 15,000 pounds.

"Trac-Tred" Turning Roll is manufactured by Aronson Machine Company, Arcade, New York.

Maintenance Workers' Torch Lights Instantly Uses "Throw-Away" Fuel Can

A versatile new portable hand torch that can be instantly lighted for any maintenance job requiring the application of heat or a hot flame has been perfected after extensive field tests with maintenance men and is now in the hands of jobbers.

It is the "Prepo" hand torch, which lights instantly with a match, burns with a clean, blue, hot flame and does away with all pouring, pumping and priming

characteristic of ordinary blow torches. "Prepo" fuel is supplied in a disposable can, much the same size as an ordinary beer can, which is sealed and locked in place as a part of the torch. When empty, the container is removed, thrown away and a new, full can of "Prepo" fuel attached.

The new "Prepo" fuel is a compound of hydrocarbons which is self-pressurizing and self-vaporizing. It is a nontoxic, nonpoisonous low pressure fuel. Packed in the new, handy container, it seals into the "Prepo" torch in such a way that when the valve is opened the burning tip can be lighted with a match as easily as lighting a gas stove. Within 30 to 60 sec. the flame achieves its maximum heat of more than 2200°.

Field tests have shown that the new torch is ideal for hundreds of jobs done daily around maintenance shops. Both torches and fuel are being marketed nationally by three leading companies. They are Maremont Automotive Products, Inc., Appleton Electric Co., and Bell & Gossett Co.

For further information write Pressure Products Corporation, 140 N. Dearborn Street, Chicago 2, Illinois.

Machine for Automatic Welding of Aluminum

Argon Metal Arc Welding of Aluminum

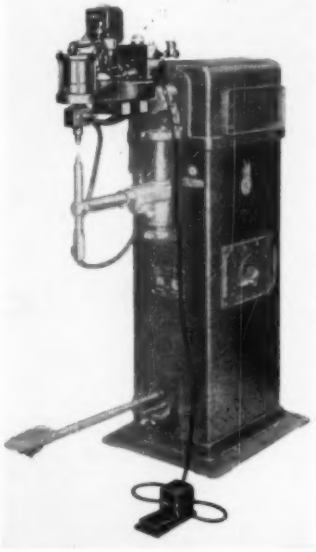
A new machine for automatic welding of aluminum by the argon shielded metal arc welding process—has been announced by The Linde Air Products Co., Unit of Union Carbide and Carbon Corp. This welding machine uses an arc maintained in a shield of argon gas between the consumable filler-metal electrode and workpiece. The electrode, supplied as a coil of wire, is deposited across the arc into the weld as filler metal. The process is applicable to either machine or hand welding, and can be used for all of the metals that are readily joined by Heliarc welding. The initial effort is being concentrated on the welding of aluminum plate. The equipment for mechanized welding is known as the "Linde" FSM-1 machine.

Welds are clean and smooth. No flux is used. The possibility of flux corrosion or entrapment is eliminated, and cost of cleaning and finishing the welds is sharply reduced. Welding is fast and weld quality high. The aluminum alloys, welded commercially by this process presently include 28, 38, 52-S and 61-S in plates $\frac{1}{4}$ to $1\frac{1}{2}$ in. thick. Almost any thickness can be welded by a suitable number of passes. With the FSM-1 machine now available, butt welding is performed in the flat position, and fillet and lap welding in the flat and horizontal positions.

To fabricators of such equipment as railroad tank cars, storage tank and pressure vessels and chemical and food processing equipment, argon shielded metal arc welding offers a low-cost, high-quality method of welding at rapid rates of production. Descriptive folder on this new process is available on request from The Linde Air Products Co., 30 E. 42nd St., New York 17, N. Y.

Weld-Air-Matic for Spot Welders

Accompanied by complete, detailed installation instructions and diagrams, a small, compact, self-contained unit is now available to add the advantages of air-pressure operation to regular foot-controlled rocker arm type spot welders. The unit is named Weld-Air-Matic, and is manufactured by the Robt. W. Hoffman Co., Inc., of Chicago.



Many of these units have been tested in operation during the past year, running on a full production schedule of 8 to 10 hrs. daily. They are making on an average of 10,000 welds per hour as proof of their ruggedness and efficiency.

The Weld-Air-Matic clamps to the upper horn of conventional rocker arm spot welders. It operates on a reduced air pressure of 15 to 50 lb., depending on the particular requirements of the welder in use. Eliminating the necessity of all rocker arm movement, the Weld-Air-Matic operates through a maximum stroke of $1\frac{1}{2}$ in. on size 1 welder, 2 in. on size 2 and $2\frac{1}{2}$ in. on size 3. A feather touch electric foot switch controls the air pressure, energizing a coil on a four-way operating valve. The unit is designed to operate in conjunction with any standard Weld Timer Control, and requires at least 4 cu. ft. of air supply per minute, with a minimum of 80-lb. line pressure.

All accessories are mounted on one strong, aluminum alloy casting. Wearing parts are oil sprayed, and there is a grease fitting for piston rod and bushing lubrication.

Weld-Air-Matic is available in three standard sizes. Further details can be obtained by writing Sales Manager, Robt. W. Hoffman Co., Inc., 32 S. Clinton St., Chicago 6, Ill.

Hard Facing Electrodes

Alloy Rods Company, 6205 W. Market St., York, Pa., has just issued a bulletin announcing completely new line of hard-facing alloy electrodes. Basic technical information is given for many applications for hard-facing in industry.

What's the right X-Ray film?

Product:
Pressure vessel
Material:
Cold rolled steel,
1-1/4 inches thick
Equipment:
200-kv x-ray unit

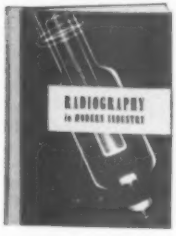
Remarks: RUSH

ANSWER:

KODAK INDUSTRIAL X-RAY FILM, TYPE K

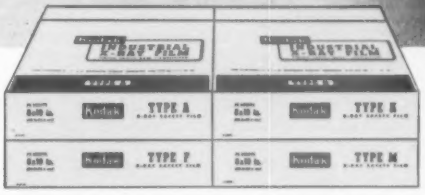
The wall of the tank was thick—the kilovoltage available was low. And the customer was impatient for delivery. So the radiographer did this job with Kodak Industrial X-ray Film, Type K.

This film, in contact with lead foil screens, has sufficiently high speed to allow reasonable exposure with equipment of moderate power. The good definition so obtained is added assurance that significant weld irregularities will not be missed.



RADIOGRAPHY IN MODERN INDUSTRY

A wealth of invaluable data on radiographic principles, practice, and technics. Profusely illustrated with photographs, colorful drawings, diagrams, and charts. Get your copy from your local x-ray dealer—price $3.00.



A TYPE OF FILM FOR EVERY PROBLEM

To provide the recording medium best suited to any combination of radiographic factors, Kodak produces four types of industrial x-ray film. They furnish the means to check welds efficiently and thus extend the use of the welding process.

Type K has medium contrast with high speed. For gamma ray and x-ray work where highest possible speed is needed at available kilovoltage without calcium tungstate screens.

Type F provides the highest available speed and contrast when exposed with calcium tungstate intensifying screens. Has wide latitude with either x-rays or gamma rays, exposed directly or with lead screens.

Type M provides maximum radiographic sensitivity, high contrast, and exceptional detail under direct exposure or with lead foil screens. It has extra fine grain and the speed is adequate for examination of light alloys at moderate kilovoltage and for much million-volt radiography.

Type A offers high contrast with about three times the speed of Type M, but with slightly more graininess. Used direct or with lead foil screens for study of light alloys at low voltages, and of heavy steel parts at 1000 kv.

Radiography...

another important function of photography

EASTMAN KODAK COMPANY
X-ray Division · Rochester 4, N. Y.

"Kodak" is a trade-mark

Kodak

PERSONNEL

Browne Moves to Boston

R. L. Browne, New England representative of National Electric Welding Machines Co. of Bay City, Mich., formerly located at Albany, N. Y. has moved his office to 10 Post Office Square, Boston 9, Mass. Mr. Browne is a member of the AMERICAN WELDING SOCIETY.

L. J. Gottschalk, Jr., Increases His Territory

L. J. Gottschalk, Jr., Chicago representative of National Electric Welding Machines Co., with offices at 2400 W. Madison St., (Room 626) Chicago 12, Ill., has expanded his territorial activities to include the Indiana territory formerly handled by Welding Equipment and Supply Co. of Indianapolis. He is a member of the AMERICAN WELDING SOCIETY.

Arcos Appointments

Arcos Corp., manufacturer of stainless low-alloy high-tensile and nonferrous electrodes, Philadelphia, Pa., announces three new appointments to its staff. They are all members of the AMERICAN WELDING SOCIETY.

Bernard E. David has joined the company as a special field engineer, located in Los Angeles. Previously, Mr. David acted as manufacturer's representative for a line of welding supplies. He was earlier connected for ten years with the Corpus Christi Oxygen Co., Corpus Christi, Tex.

Bernard E. David

Walter Gordon List will act as special field engineer in the Ohio-Western Pennsylvania territory, assisting Williams & Co., Inc., of Pittsburgh, Pa., in the sale of Arcos electrodes. For the past five years, Mr. List has been covering the Philadelphia territory. Before joining Arcos he was associated with the Gulf Oil Co.

W. Gordon List

New Arcos sales representative is J. J. Schlass, who will work in the Philadelphia district. Mr. Schlass was previously associated with Hobart Welder Sales and

J. J. Schlass

Service, and with Williams & Co., Inc., of Columbus, Ohio. He also worked as a welding engineer with Battelle Memorial Institute and with the Caterpillar Tractor Co.

Additions to Lincoln Sales Engineering Staff

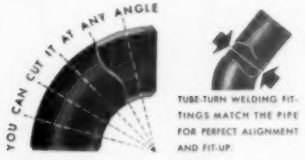
The welding engineering staff of several of the district offices of the Lincoln Electric Co., Cleveland, Ohio, have been increased recently.

J. W. Brooks is now serving the Boston area as welding engineering. Brooks is a graduate of Cornell University in Mechanical Engineering.

HOW TO SIMPLIFY ODD-ANGLE PIPING

The ease with which pipe can be installed at odd angles for compactness is an important reason for the widespread preference for Tube-Turn Welding Fittings.

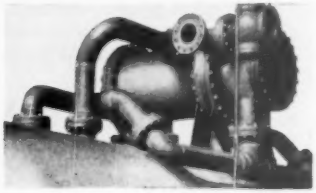
For example, one of the country's leading consulting engineers (name upon request) states: "We employ a great number of experienced welders in all parts of the country. They all prefer Tube-Turn Welding Fittings because many of the fittings we use must be cut to odd angles. When lining up the fittings, cutting them and placing them into the line, our welders say they are more



sure of accurate alignment and fit-up with Tube-Turn Welding Fittings than with any other make."

There's good sound reason behind this preference. Tube-Turn Welding Elbows and Returns are formed to give you *true circularity . . . accurate curvatures and center-to-face dimensions . . .* and *absolute uniformity of wall thickness. Hence, you can cut a Tube-Turn Welding Elbow or Return to any odd angle required and it will line up perfectly with the pipe.*

Tube-Turn Welding Fittings are available in a *complete range of sizes, shapes and materials.* For speed, simplicity and versatility in piping installations, be sure you get *genuine* Tube-Turn Welding Fittings.



Tube-Turn Welding Fittings simplify the fabrication of intricate piping system designs such as the installation shown above. Their true circularity and uniform wall thickness permit cutting and welding them at any odd angle.

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J. J. Chemerys is serving industrial accounts in the Syracuse territory. He is a graduate of Penn State in Industrial Engineering and worked for the Joy Mfg. Co. before joining Lincoln.

Both are members of the AMERICAN WELDING SOCIETY.

OBITUARY

L. H. Buckmaster

L. H. Buckmaster, 43, District Manager for Lincoln Electric in Detroit, died March 27 as a result of injuries received in an automobile accident. He had been in the Lincoln sales department for 20 years, 16 of which were spent in the Detroit area in the development of welding in the important tool and automotive industries.

Through his study of manual and automatic welding processes and manufacturing methods as they have developed during the past 20 years, Buckmaster became recognized by automotive engineers as an authority on welding in automotive manufacture. His services as a consultant on the application of automatic welding were valued throughout the industry. He was also recognized as an excellent organizer and trained many young engineers in the field of automotive welding application.

He was a Mechanical Engineer, a graduate of Iowa State College. He started with Lincoln Electric in November of 1929 and went immediately to the Detroit area as a sales engineer. From 1938 to 1942 he served the Pittsburgh territory, engineering welding applications in the major industries of that area. He returned to Detroit in 1942 as District manager. Mr. Buckmaster was a member of the AMERICAN WELDING SOCIETY.

He is survived by his widow, Bernice and three children, Roger, Allen, and Nancy.

LIST OF NEW MEMBERS

April 1 to April 30, 1950

ANTHONY WAYNE

Aldrich, Robert (B)

ATLANTA

Reavis, Leland H. (B)
Smith, Floyd A. (B)
Williams, Jay D. (B)

ARIZONA

Bode, Paul (C)
Cornelius, J. F. (C)
Crawford, Lee G. (C)
Dye, Gil V. (B)
Dye, Gil V., Jr. (C)
Overstrut, Benjamin Edward (C)
Thomas, Edward L. (C)

BIRMINGHAM

Hanson, Neil H. (B)

CLEVELAND

Driscoll, J. M. (C)
Fauser, William J. (B)
Laird, L. J. (B)
Newman, Robert J. (C)

COLORADO

Sinnott, L. J. (B)

COLUMBUS

Kutchera, Richard E. (D)
Young, Virgil L. (D)

DAYTON

Gervins, Albert I. (D)
Gunner, John W. (D)

DETROIT

Jerome, Michael J. (B)
Lortie, Charles F. (B)*
Segedi, Mathew (B)

HARTFORD

Brophy, G. R. (B)
Oliva, Allie D. (C)

HOUSTON

Jolly, J. C. (B)
Myrow, C. F. (B)
Shaw, S. E. (B)
Stockton, Roy G., Sr. (B)

INDIANA

Collora, N. A. (B)
Martin, Charles E. (C)

LONG BEACH

Recla, E. P. (C)
Hughes, George E. (D)

LOS ANGELES

Eagle, John M. (B)

MAHONING VALLEY

Jaeger, Ernest W. (C)
Thompson, Wendell L. (B)

MARYLAND

Daneryd, Lars Erik (C)
Sittler, Howard L. (C)

MILWAUKEE

Dennison, Peter G. (B)
Eickelberg, E. Stuart (B)

NEW JERSEY

Cross, A. Stanley, Jr. (C)
Johnson, Charles E. (C)

NEW ORLEANS

Strassberger, John W. (C)

NEW YORK

Clack, George Eric (C)

NIAGARA FRONTIER

Bevington, Joseph (B)
Woodward, Robert C. (B)

NORTHERN NEW YORK

Perkins, Phillip (C)

NORTHWESTERN PA.

Brinig, Eugene J. (B)
Buck, Everett R. (B)

OKLAHOMA CITY

Brookshire, Granville E. (D)
Funk, Marion P. (B)

PHILADELPHIA

Mc Kiernan, James J. (C)

PITTSBURGH

Ciarkowski, Theodore (B)
Godez, Anton Martin (C)
Martin, David I. (B)
Steele, Arthur E. (C)

ST. LOUIS

Carnall, John T. (B)

SALT LAKE CITY

Bouck, A. S. (B)
Call, C. Roldo (B)
Davis, Leo R. (B)
Francom, Hudson F. (B)
Lombardi, Louis (B)
Rosenblatt, Donald (B)

SAN FRANCISCO

Howard, Marvin Lee (B)

SUSQUEHANNA VALLEY

Altholz, Edgar (C)
Benscoter, Rockwell W. (C)
Mieding, George L. (B)

SYRACUSE

Blixt, Felix O. (B)
Drew, Bidwell P. (C)
Speirs, John R. (C)

TOLEDO

Barclay, R. J. (B)

TULSA

Billings, Robert K. (B)
Bradley, Kenneth N. (B)
Breeding, E. A. (B)
Champion, Ward M. (B)
Ellis, Judson J. (B)
Estes, Ted I. (B)
Grace, Oscar R. (B)
Jaggers, W. H. (B)
Walcott, Jack (B)

WASHINGTON

Taylor, Woodrow L. (B)

WICHITA

Farley, J. W. (C)
Kelly, Leo M. (B)
Newby, Chester C. (C)

NOT IN SECTIONS

Bush, J. M. (B)
Dibos, Eduardo, Ch. (B)
Nagai, Nobuo (B)
Soderstrom, Ingvar (C)

Members Reclassified

During the month of April

CINCINNATI

Holt, Donald C. (C to B)

CLEVELAND

Fulton, Edward G. (C to B)
Garber, Daniel C. (D to C)

NORTHWEST

Neemes, J. C. (C to B)

PHILADELPHIA

Dawson, Lester K. (C to B)

WESTERN MICHIGAN

Ogden, Roland H. (C to B)

* March New Member

abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 10, D. C.

2,501,724—Apparatus for Thermochemically Cutting Metal—Howard G. Hughey, Fanwood, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

A torch tip having a discharge face which is elongated in the direction of the length of the cut to be made in a workpiece is disclosed in this patent. Such torch tip has a plurality of discharge jets formed in alignment therein and alternate jets are provided with a supply of preheat gases whereas the remaining alternate jets have oxygen supplied thereto.

2,501,845 — Electrode Holder for Spiral Pipe Machines—Jonathan Roy Freeze, Middletown, Ohio, assignor to Armco Steel Corp., a corporation of Ohio.

In this machine, a bending knee is provided about which metal stock is formed into a helix with substantially meeting edge portions and an extension is positioned on the bending knee. An electrode holding member is adjustably positioned on the bending knee and means are provided for controlling this electrode holding member from the entrance end of the bending knee.

2,501,954—Electric Arc Drill—Ian C. McKechnie, Roy E. Blue and Lester E. Oliphant Detroit, Mich.

This patent discloses a method for removing material from a workpiece and it comprises creating a series of intermittent electric arcs between a tool and a workpiece by means of rapid pulsations in a unidirectional electric potential connected between a tool and the workpiece. A coolant may be passed through the arc to aid in extinguishing an arc set up between the tool and workpiece.

2,502,073—Gas Torch Lighter—Kenneth H. Black, Port Clinton, Ohio.

A special lighter of the class indicated is disclosed in this patent.

2,502,604—Heating Torch—Louis V. Tanner, Cleveland, Ohio.

Tanner's heating torch includes a tubular housing which has an end wall at one end and an open mouth at the other end, there being an opening through the end wall for admission of compressed air. A partition is formed in the housing parallel to and spaced a short distance from the said end wall with an opening being provided therein for the admission of an air jet into the tubular housing. A second opening is provided in the side of the tubular housing in front of the partition and communicating with the atmosphere for the aspiration of air into the housing by the air jet. Inlet means for gaseous fuel are positioned in front of this last-named opening.

2,502,646—Arc Welding Circuit—Dean C. Girard, San Leandro, Calif., assignor by mesne assignments to National Cylinder Gas Co., a corporation of Delaware.

In this arc-welding circuit a transformer is provided and the primary thereof is connected to a power source. A high reactance winding is connected in series with the primary of the transformer for lowering the welding voltage to a lower-than-normal value. This winding has sufficient reactance to maintain a smooth arc across the welding electrodes at this lower-than-normal voltage value. Relay means responsive to the voltage across the secondary winding are provided for connecting the primary winding directly across the power source and eliminating the reactance from such circuit.

2,502,876—Electric Resistance Spot Welding Apparatus—Henry A. Mullen, Milwaukee, Wis., assignor to Ampco Metal, Inc., Milwaukee, Wis., a corporation of Wisconsin.

This patent covers an electrode tip which is made from a solid conductive body of generally cylindrical form and made from bar stock. The tip is tapered at both ends and has a plurality of longitudinally extending, circumferentially spaced, parallel grooves provided therein.

2,502,877—Welded Penstock—Howard H. Needham, Wauwatosa, Wis., assignor to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

Needham's patent covers a special cylindrical wall structure of the type indicated. Butt welds are provided between adjacent portions of the cylindrical wall.

2,502,887—Resistance Welding Apparatus—Alexander Rava, Jersey City, N.J.

This resistance welder includes a circuit wherein a welding transformer, an energy storage device and a power transformer are provided. Additional means are present for successively charging the said device alternately to opposite polarity from the power transformer while other means discharge the device by surges of current alternately in opposite vectorial directions through the primary of the welding transformer in timed relation with the phase of voltage in the power transformer. Unidirectional means effect inverse charging of the energy storing device during the collapse of the magnetic field in the welding transformer.

2,503,382—Electrode Tip Cleaning Device—Simon Fisher, Bay City, Mich., assignor to National Electric Welding Machines Co., Bay City, Mich., a corporation of Michigan.

In this patented cleaning device, a pair of head plates are provided and are movable toward and away from each other in a welding machine. The shaft is supported on one of the head plates and has a cleaning head secured to an end thereof. Resilient means are provided for urging the cleaning head to engage with the electrode in the welding machine in order to clean same.

2,503,608—Weldable Nickel Base Alloy—Robert T. Banister, Chesterland, Ohio, assignor to Thompson Products, Inc., Cleveland, Ohio, a corporation of Ohio.

Banister's patented alloy is particularly suited for use in making exhaust valves for internal combustion engines and the alloy includes 20–30% of chromium, 45–65% of nickel, 6–15% of molybdenum, 1.5–2.5% of carbon and small amounts of calcium, zirconium and silicon, with the balance being iron.

2,503,729—Electric Welding Torch—Frank Gruszecki, Buffalo, N. Y., assignor of one-half to Henry Rothernberg, Buffalo, N. Y.

This novel type of a welding torch includes a tubular handle which has a pair of relatively movable conductor bars supported at their inner ends on the tubular handle member. The outer ends of the conductor bars provide electrode holders normally disposed in spaced relation. Means are provided on the handle member for providing a ready connection to one conductor bar so that it can be moved toward the electrode holder positioned by the other conductor bar in order to form an arc between the electrodes positioned thereby.

2,504,607—Heavy-Duty Welding Rod Holder—Martin Wells, Pasadena Calif.

Well's patent covers a special type of a heavy-duty welding rod holder.

2,504,630—Coated Self-Starting Welding Rod for Touch Arc Welding—Henri Bienfait, Willem Pieter van den Blink, and Simon Dirk Boon, Eind-

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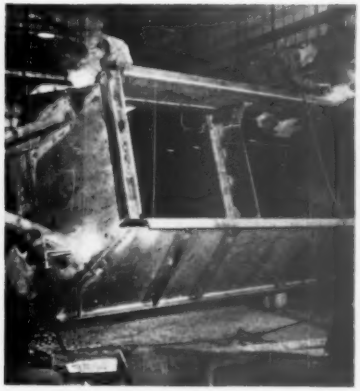
TYPE W-22—AWS E6010, d-c reverse polarity, all positions; recommended for all types of joints in mild steel. Produces welds of excellent appearance, high tensile strength, ductility, and high impact resistance. Typical applications include pipe-lines, shipbuilding, structural frames, tanks and pressure vessels.

TYPE W-27—AWS E6020-30, a-c/d-c, flat and horizontal positions; recommended for high-speed production of butt and fillet welds on mild steel. Permits higher speeds than other production electrodes, making it particularly suited to jobs where distortion must be minimized.



TYPE W-28—AWS E6012, a-c/d-c straight polarity, all positions. Designed for mild steel, general-purpose welding, this electrode possesses a very stable arc without excessive arc force. Excellent fusion, good appearance with minimum convexity, and easy slag removal.

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1. Greater welding flexibility—either a-c or d-c, all positions.
2. Weld deposits are completely machinable and color matching.
3. Exceptionally stable arc—means smoother operation and weld deposits of machine-like appearance.
4. Increased resistance to cracking.
5. Excellent low-current operation—minimizes brittle heat-affected zone in base metal.

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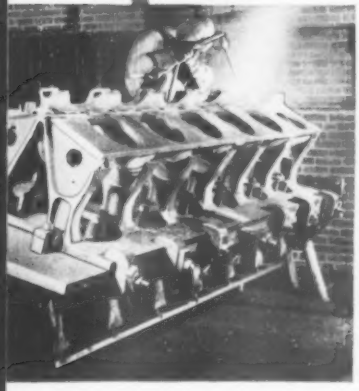

TYPE W-32—AWS E6016 or E7016 a-c/d-c reverse polarity, all positions; a low-hydrogen electrode providing higher welding speeds, increased impact strength, and greater ductility. Eliminates underbead cracking when welding medium-carbon steels, sulphur-bearing steels, etc.

TYPE W-2347—AWS 347-16, a-c/d-c reverse polarity, all positions. A *stainless-steel* electrode for welding AISI Types 302, 304, 308, and 347 stainless base metal. (For other special types of stainless, G.E. offers a complete line of stainless electrodes to match specific analyses.)

TYPE W-94—For building up or hard-surfacing areas requiring high abrasion and impact resistance, you can't beat W-94. It's an all-position rod especially suited to welding plowshares, hammer mills, scarifier teeth, tractor grousers, rock crushers, etc.

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3. **Welding Journal each year gives its readers the results of more than a million dollars' worth of research.**

4. **Welding Journal contains news articles and regular feature sections of direct interest to the practical welder, as well as welding engineers, engineers who are interested in welding, and designers.**

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WELDING JOURNAL

hoven, Netherlands, assignors to Hartford National Bank and Trust Co., Hartford, Conn., as trustee.

This novel welding rod has a coating which comprises from 20–50% of iron powder and from 5–80% of a special kind of a semiconducting titanium oxide.

2,504,711 — Automatic Arc-Welding machine—Sven Lundahl and Carl Lundahl, Malmo, Sweden, assignors to Allmanna Svenska Electriska Aktiebolaget, Vasteras, Sweden, a Swedish corporation.

This welding machine includes an endless member which runs over wheels positioned in the welding machine and has electrode holders pivotally secured thereto. An electrode magazine is attached to the casing around the welding apparatus and supplies electrodes successively to the electrode holders. Means are provided on the guide member for feeding electrodes into the electrode holder for holding back the electrodes until a predetermined force is exerted on the electrode. Additional means clamp the upper end of the electrode during its motion against the welding surface and during the removal of the electrode end from such welding surface.

2,504,753 –Welding Method and Apparatus—William H. Suydam, Jr., Glen Ridge, N. J., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

The method of this patent is particularly directed to connecting two conductors of different diameters wherein an axially directed pocket is formed in the end portion of the larger conductor and the smaller conductor is inserted therein and welding current is sent through the conductors. Pressure is applied to the sides defining the pocket formed in the larger conductor to cause such pocket to grip the smaller conductor tightly.

2,504,777—Welding Cable—Frederick S. Wreford, Detroit, Mich.

A special type of a cable particularly suitable for use in welding operations is disclosed in this patent.

2,504,802—Brazing Flux—Joseph G. Christ, Pittsburgh, Pa., and Russell L. Ferguson, Bronx, N. Y., assignors to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

This brazing flux is composed of about 60 to 70% of boron oxide, ½ to 10% lithium oxide, at least 10.2% but not over 23% sodium oxide, and at least 7% but not over 35% of potassium oxide, all percentages being by weight.

2,504,837—Welding Rod Holder—Joseph A. Hills, Dayton, Ohio.

Hill's welding rod holder is manually controlled and has a rockable actuator therein. Electrically responsive means are provided for energizing the actuator to withdraw the welding rod holder away from the work to strike an arc between the welding rod and the work. An electric energizing circuit is provided for the said energization means and is closed by contact of the rod with the work.

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Time after time in shops, foundries and metal salvage yards where heavy work and rough use is the rule, it's the "75" that's preferred. Yet despite its ruggedness, the "75" performs with knife-like precision. It cuts clean edges with an absolute minimum of kerf. It cuts faster. It cuts easier.

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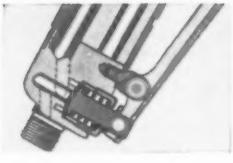

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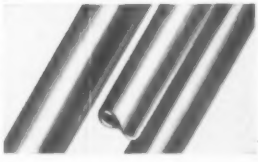

Triangular Tube Construction gives exceptional rigidity and strength. Tubes are silver-brazed to head and body for maximum durability. Accurate needle-valves have stainless steel conical stems.

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SECTION ACTIVITIES

prepared by C. M. O'Leary

Anthony Wayne

The photograph of the "Atomic Hydrogen Welder" shows the prize which the Indiana Section was most fortunate to win at the Anthony Wayne Section welding quiz. By the expressions on the faces of the Indiana team one can see that after careful study and intensive investigation they are still somewhat bewildered by this unusual and awe-inspiring welding (?) device.

The members of the Indiana team shown (who have, incidentally, each received a minimum of one electric shock from the gadget) are, left to right: Ray Wirt, Delco-Remy Division, G.M.C.; Ed Holt, P. R. Mallory & Co.; Carl Sauer, Reuas Engineering Co.; and Ernie Goehringer, The Lincoln Electric Co.

The April Meeting of the Anthony Wayne Section was held on Friday, April 21st, in the Fort Wayne Chamber of Commerce Bldg. Following a Buffet Dinner, the members and their guests were entertained by Miss Jackie McCoy and her accordian.

The main technical speaker, E. B. Brown of The American Brass Co., Detroit, Mich., was then introduced. Those present enjoyed a most interesting film entitled, "Copper, Mining, Smelting & Refining." Mr. Brown then presented a very interesting talk on Braze Welding in Production and illustrated his talk with up-to-date and very recent slides. It was explained and shown how braze welding of steel tubular members in the production of modern steel furniture saved weld time, preparation time and finishing time. For those present who normally think of this process for maintenance welding only, it was most enlightening to learn what may and can be done in the way of production welding. A half-hour question-and-answer period rounded out this highly educational meeting.

Arizona

The regular monthly meeting of this Section was held in the Verde Room of the Hotel Westward Ho on April 19th. There were approximately fifty-five in attendance.

Speaker was Richard Kilgore, Welding Engineer of the Los Angeles office of The Lincoln Electric Co. Mr. Kilgore spoke on the subject "Development and Trends of A.-C. Welding." He very capably showed the Section how power requirements are less with a.-c. welding compared to d.-c; also how speed of welding is increased by the avoidance of arc blow which is characteristic of d.-c. welding and how it has been successfully overcome. He discussed open-circuit voltage of a.-c. machines and explained that both a.-c. and d.-c. machines are practically identical as far as safety to operator is concerned.

After an enthusiastic discussion which followed his talk Mr. Kilgore was thanked by the chairman, Ralph Hoffman, and a sound film was shown titled "Distortion—Its Prevention and Control" by courtesy of The Lincoln Electric Co.

Boston

At the annual meeting of the Boston Section held on April 10th in the Campus Room, Graduate House, M.I.T., the following officers were elected for the coming year:

Chairman, James Donovan, Artisan Metal Products Co.; *Vice-Chairman*, H. Hugo Stahl, The Lincoln Electric Co.; *Sec.-Treas.*, Louis I. Dexter, Rumford Steel Products, Inc.; *Trustee*, L. F. Jackson, The Linde Air Products Co.; *Directors* (for 2 years)—F. L. Brandt, Jr., Thomas B. Walsh, Albert O. Wilson, Jr.

Guest at the dinner was Carroll Farwell, President of the Engineering Societies of New England. Dinner speaker was Elliott Blackiston, well-known dog fancier and breeder, who brought along with him "Blitz," a Doberman Pinscher, winner of many blue ribbons in the obedience class at important dog shows and used to help train dogs in World War II.

Technical speaker was J. E. Revelle, Contracting Engineer, Chicago Bridge and Iron Co., Boston Office. Mr. Revelle presented an interesting, clear-cut talk on "Welded Pressure Vessels and Waterspheres."

Chairman Rugg before retiring from service to the Section, covering a span of about 18 years, made a few remarks.

Chicago

The regular monthly dinner meeting of the Chicago Section was held on March 17th at Burke's Grill, with an attendance of 30 at dinner and 100 at the technical session. Dr. John M. Parks, Armour Research Foundation, spoke on The Metallurgy of Ferrous and Nonferrous Welding. A film, Highlights of Europe, was also shown.

Dallas

The April 19th meeting of the Dallas Section was held in the Auditorium of the Lone Star Gas Co. Dinner was served in Earl's Steak House. D. D. Kuhn, of Carnegie-Illinois Steel Corp., spoke on "Welding and Fabrication of Stainless Steel."

Refreshments were served after the meeting.

Dayton

Current trends in cost-cutting developments resulting from the use of stud welding were reviewed at the April 26th meeting by Robert C. Singleton of Lorain, Ohio, manager of Customer Engineering Division of the Nelson Stud Welding Division of Morton Gregory Corp.

New England Meeting—Hartford Section. Left to right—O. B. J. Fraser, J. Light and Philip Coombs

Mr. Singleton traced the history of stud welding developments starting with early Bureau of Ships experiments, through Ted Nelson's first practical portable welding gun, through the expansion of the war years, and up to its present widespread use in many industries. He pointed out that the process was developed originally as a means of securing wood decking to steel ship hulls for the Navy before World War II. Since the war, it has found an ever-broadening field of application in construction, railroad, automotive, electrical and other production industries. More recent developments in stud welding alloy steels and nonferrous alloys were also explained. Mr. Singleton also showed a sound color film on "Split-Second Fastening."

Results of the election of officers were announced by retiring Chairman John Blankenbuehler as follows: *Chairman*, D. H. Rickard, Andrew Plocher Sons Co.; *Vice-Chairman*, C. D. Schultheis; *Secretary*, E. M. Garber, Hobart Brothers Co.; *Treasurer*, G. I. F. Theriault; *Directors* R. E. Bowman and H. G. Weiler.

Hartford

A New England Meeting was held on April 13th with dinner at The Rockledge Country Club.

The meeting started off with a field trip through the Royal Typewriter Plant which was most interesting. The Royal Typewriter Co. were excellent hosts. With all the thousands of parts being made, then assembled and checked, the members all agreed that their own businesses were not nearly so complicated.

From there the members walked to the G. F. Heublein & Bros. Plant. All were impressed with the cleanliness and equipment for handling and bottling these products. At the closing of the trip each member was given a sample of their A-1 Sauce, A-1 Mustard, and a fifth of London Dry Gin.

Upon returning to the Rockledge Country Club, where registration was held, the Section acted as host for a Cocktail party. Dick Studzinski and his wife Ann, with Ed Lally, entertained the entire group through dinner with lots of local color.

Philip H. Coombs, Economic Adviser to Governor Bowles of Connecticut, gave an excellent talk of the proposed steel mill in New England. Everyone was most interested and received Mr. Coombs well. The balance of the evening was spent meeting old friends. The photograph herewith shows speaker Philip Coombs and O. B. J. Fraser, President of the A.W.S., with J. Light, Chairman of the Hartford Section.

Past chairmen pins were presented to Messers J. W. Mortimer, M. Powell, R. Florian and S. S. Adelson.

Houston

The Officers and Directors had a dinner meeting with O. B. J. Fraser, President of the A.W.S., on March 27th. His visit was helpful and enjoyed by all.

The regular monthly dinner meeting was held on April 20th at Ben Milam Hotel. C. D. Kuhn, Products Representative, Stainless Steel Division, Carnegie Illinois Steel Corp., spoke on "The Welding and Fabrication of Stainless Steel."

Kansas City

The Kansas City Section held its April meeting on the 18th at Fred Harvey's, Union Station, Kansas City, Mo.

J. E. Dato, Service Supervisor of the South Western Division for The Linde Air Products Co., was the guest speaker. His subject was "Advantages and Methods of Oxyacetylene Cutting." Mr. Dato is a splendid speaker and has the background for informative and interesting discussions.

Lehigh Valley

The Lehigh Valley Section held its Annual Meeting and Ladies Night on Monday, May 1st, at the Hotel Bethlehem, Bethlehem, Pa. Q. E. Charlesworth presided at the meeting. T. K. Leinbach, Superintendent of the Community General Hospital, Reading, Pa., gave a very interesting talk on "Something to Think About." He told of the need for a better outlook on national indifference, prejudice and selfishness in order to make possible a more optimistic view of the future. He stressed the importance of these changes for the development of a higher type of citizen to prevent another world conflict.

Refreshments and dancing followed with the members and their ladies having a very enjoyable evening.

The photo below shows the speaker and newly installed officers and was taken at this meeting. Seated left to right are: J. R. Fairhurst, *Chairman;* T. K. Leinbach, *Speaker.* Standing: L. P. Elly, *Vice-Chairman;* R. A. Bartholomew, *Director;* Julius Naab, *Secretary-Treasurer.*

The following officers were installed for the 1950–51 season: *Chairman*, J. R.

Lehigh Valley Meeting

Fairhurst, Ingersoll-Rand Co.; *Vice-Chairman*, L. P. Elly, Bethlehem Steel Co.; *Sec.-Treas.*, Julius Naab, Ingersoll Rand Co.; *Past Jr. Chairman*, Q. E. Charlesworth, Bethlehem Steel Co.; *Directors* (for 3 years), R. E. Somers and R. A. Bartholomew.

Louisville

The April 25th meeting consisted of a series of discussions based on talks by four members on various types of welding. Vice-Chairman Mason S. Noyes questioned each speaker to draw out the pertinent information from each talk and guided the discussion from the floor.

Clarence E. Schiller talked on "Gas Pipe-Line Welding," L. G. Rickert spoke on "Welding of Stainless Steel," M. P. Corcoran, Jr., on "Copper Joining," and E. B. Cox of Newark, N. J., on "Welding and Fabrication of Manganese-Nickel Steel." Each man spoke from his own experiences which made the program interesting and profitable.

A social hour and lunch followed the talks.

Mahoning Valley

The monthly meeting was held on Thursday, April 20th, at the Tod Hotel, Youngstown, Ohio. Technical speaker was R. W. Tuthill of the Welding Division, General Electric Co., Fitchburg, Mass. Mr. Tuthill's talk on "The Use of Inert-Arc Welding and Its Application" was very well received by the group and more questions were asked during the question-and-answer period than in any meeting of the year. Mr. Tuthill is a very able speaker and has a very wide knowledge in the application of inert-arc welding.

The March meeting was a joint meeting with the A.I.E.E. and a very interesting discussion of television was given by Richardo Muniz, General Manager of the Television Division of the Allen B. DuMont Laboratories. This program was also very satisfactory in that Mr. Muniz was able to answer questions of both a general and a very technical nature.

Maryland

The regular dinner meeting of the Maryland Section was held on April 21st at the Engineers' Club, Baltimore. Jack Dunn of the "Baltimore Orioles" gave a résumé of the preparations for the coming season, which was well received by the members. From the number of questions and the discussion, it often seemed dubious as to whether this was a welding or a baseball meeting.

Prior to the technical session, the Chairman announced that the Cumberland Valley division now has 22 members in good standing and the encouraging rate of growth leads to the prediction of further gains. This is further supported by the exceptionally large audiences at the regular meetings held in Hagerstown.

The technical session was covered by T. B. (Ted) Jefferson, Editor of *The Welding Engineer*. His talk, "Welding, A National Necessity," brought out the important role maintenance welding plays in the welding field as a whole. At the initiation of welding, in the dark ages of the uncoated rod, maintenance welding was about the only field in which welding was tolerated. It grew in reliability apace with advanced methods to become one of the prime maintenance tools. The audience followed Mr. Jefferson's lucid exposition, appreciating his easy, good humor, which facilitated the absorption of the principles of good maintenance welding. The session closed with a lively discussion.

Michiana

"Properly applied, welding can be a tool of enormous value, but if used without suitable consideration, it can cause all kinds of trouble." Thus did Charles H. Jennings, Welding Manager of Westinghouse Electric Corp., Buffalo, N. Y., set the stage for his talk to the Michiana Section on "Plan for Welding." Given before the April 25th meeting, Mr. Jennings stressed the fact that successful production of welded parts can only be accomplished by total cooperation between the designing, processing and manufacturing departments.

Mr. Jennings pointed out the role of the A.W.S. in the standardization of welding rods and commented on the reason for all the various types. A. c. and d. c., manual and automatic, metallic arc or inert-gas-shielded arc, each has its own place, and when the engineer knows what he needs and how it should be done, and the operator knows what is required, welding becomes the tool which can make your product better and cheaper!

New Jersey

The April 18th meeting was opened with the showing of the film, "Faster Than Sound," which depicted the testing of a pilot model supersonic rocket plane in Great Britain.

After the film was shown, the Section business was dispensed with and several visitors were introduced, including Simon A. Greenberg, Editor of the Third Edition of the *Welding Handbook*. The door prize was won by W. Dolan.

The feature of the evening was a quiz program, the "1950 Battle of the Sections," with contestants from Bridgeport, New York, Philadelphia and New Jersey Sections. The four Sections were represented by the following: Bridgeport—Linde Bock, R. S. Pulver, J. Mitchell; New York—Jay Bland, R. S. Donald, A. N. Kugler; Philadelphia—E. Elwood, A. J. Raymo, A. Schaeffler; New Jersey—J. H. Humberstone, K. Koopman, R. E. Powell. The judges were O. Frederick, G. F. Mulligan, and A. M. Setapen. J. Lyell Wilson, who conducted last year's "Battle," in New York, was again drafted by popular request to act as Moderator.

The quiz was conducted by asking each team one question from each of six categories. When the spokesman for a team completed his answer, the other teammates were permitted to add further. Other teams were also permitted to add to the answer providing the five-minute period allowed for each question had not elapsed.

The six categories from which the questions were drawn are: (1) Oxygen cutting, (2) oxyacetylene welding, (3) electric welding with covered electrodes, (4) submerged-melt welding, (5) inert-gas tungsten-arc welding and (6) resistance welding.

The New York Section's team won the contest and each member on this team received a suitably engraved cigaret lighter as a prize.

New York

On April 10th the New York Section participated in a very successful joint meeting with the New York Chapter of the American Society for Metals. At this meeting the speaker was Dr. G. E. Claussen, Metallurgist, Reid-Avery Co., Dundalk, Baltimore, Md. Dr. Claussen chose as his topic, "Recent Welding Developments Affecting the Metal Industry."

In his comprehensive paper, Dr. Claussen touched upon the recent progress made in the development of the various welding processes, as well as discussing design problems and the welding and cutting of stainless steels. Dr. Claussen included in his talk a discussion of the inert-gas shielded arc-welding processes, pressure

New Jersey Meeting

welding, and the recent development in "cold" welding, to mention but a few of the highlights of his talk. He explained the methods presently used for cutting stainless steels by the arc-oxygen method. A brief discussion of surfacing by welding concluded Dr. Claussen's interesting talk.

Prior to the presentation of his paper, Dr. Claussen showed a motion picture entitled "The Welding Arc," which in slow motion revealed the action of the arc during an actual welding operation.

H. R. Clauser, Managing Editor, Materials and Methods, was the Technical Chairman for the meeting, introducing the speaker and conducting the discussion period which concluded the meeting. The meeting was held at the Building Trades Club in New York.

Northern New York

The March meeting of this Section was held at the Circle Inn, on March 30th. The after-dinner speaker was Peter T. Holdcraft, who is associated with the British Welding Research Assn. His humerous and enlightening talk was on his first impressions of the United States. The technical session was addressed by Dr. Albert Muller, Research and Development Engineer with the Air Reduction Co. His talk on "Inert-Gas-Shielded Metal Arc Welding" presented numerous applications for this new and versatile addition to the welding field.

The meeting was very well attended with approximately 85 people for the technical lecture.

The April meeting was held on the 27th at the Stanley Club in Pittsfield, Mass. A very interested audience of 22 persons heard Pierre LaGrange from Brussels, Belgium, as after-dinner speaker offer his impressions of the United States.

Leon C. Bibber, of Carnegie Illinois Steel Corp., was the technical speaker for the evening. He spoke on "The Effect of Welding and Other Local Heating Processes on Residual Stress and Dimensional Changes in Steel." His excellent review of fundamentals in metallurgy was well received by the audience.

Northwest

The April meeting of the Northwest Section met in the Covered Wagon in Minneapolis on Monday, April 10th. The host for the Happy Half Hour preceding dinner was Machinery and Welder Corp., represented by Ray Schawbe.

Committee reports were received from Elmer Hixson on his progress to date in modernizing the Building and Boiler Codes in Minneapolis. Mr. Schawbe reported on recent additions to the membership which included some twenty individuals in recent weeks.

The dinner was followed by a talk by Patrick S. Doyen, Field Engineer, Welding Equipment and Supply Co. of Detroit, Mich. Mr. Doyen spoke on tool and die welding.

Oklahoma City

The Oklahoma City Section convened at 7:30 P.M. in the Biltmore Hotel on April 18th. There were 28 in attendance. The speaker for the evening was C. D. Kuhn who is associated with the Stainless Steel Division, Tennessee Coal, Iron and Railroad Co. of the Carnegie Illinois Steel Corp., Houston, Tex. Mr. Kuhn's paper was presented in such a way that it would be received by anyone who is concerned or interested in welding or fabricating stainless steel. His paper covered the field in general and was quite educational.

Pascagoula

J. G. Magrath, Secretary of the A.W.S. was guest of the Pascagoula Section on Sunday and Monday, April 16th and 17th, and was principal speaker at the reactivation dinner meeting Monday evening at the Country Club. Mr. Magrath spoke on the objectives of the A.W.S. and of the benefits to be derived from membership. He pointed out a few inconsistencies in building and traffic codes which deny welding the full privilege of its importance. The A.W.S. is a nonprofit society of individuals who have banded themselves together for the purpose of promoting welding, carrying on welding research and removing the discrimination against welding, he said.

The tangible benefits to be drived from membership are, among others, Mr. Magrath said, THE WELDING JOURNAL, outstanding monthly professional society magazine in the country; the *Welding Handbook*, the most complete and authoritative book on welding in the world. The most important intangible benefit, he said, is the opportunity of meeting to exchange professional ideas with men in other fields of industry.

Many out-of-town guests were present.

Philadelphia

A. N. Kugler, of the Air Reduction Sales Co., discussed the subject of "Brazing and Braze Welding" in the light of the accepted definitions of the A.W.S., at the April 17th meeting. Mr. Kugler discussed each process separately from the design and application points of view, stressing the particular features and advantages of each process.

Slides were used to illustrate the lecture and to point out in detail the features and typical applications of each process.

Because of his thorough knowledge of both processes, Mr. Kugler was able to give the audience a clear-cut story on the subject. The questions which followed indicated a thorough interest by the audience.

The following officers have been elected by the Philadelphia Section for the 1950–51 season: *Chairman*, O. C. Fredericks; *Vice-Chairman*, K. Wm. Ostrom; *Secretary*, J. S. Douglas, The Linde Air Products Co.; *Treasurer*, E. R. McClung, Lukenweld, Inc.

Toledo

The April 12th meeting was held at the Commodore Perry Hotel. The speaker, Siebert Schneider, of the Frigidaire Division of General Motors Corp., Dayton, Ohio, was introduced by Chairman Snell. Mr. Schneider's topic was, "Maintenance and Service of Resistance Welders." Mr. Schneider, with 17 years' experience in this line, was well versed on the subject. Slides were used during the entire talk to illustrate production methods, proper fixtures and maintenance. Following the talk a thirty-minute question period followed.

Tri-State

The April 27th meeting held in Owensboro, Ky., was sponsored by the Modern Welding Co. with a barbecue for members and guests. The World's largest pipe line was discussed. A film on the subject was also shown.

Western Massachusetts

On Tuesday evening, April 11th, at the Hotel Sheraton in Springfield, Mass., the Western Massachusetts Section heard an interesting lecture by F. E. Garriott, of Ampco Metal, Inc., of Milwaukee, Wis.

The subject of Mr. Garriott's talk was "Welding with Bronze Electrodes." Mr. Garriott first pointed out some of the advantages which are peculiar to the use of copper-base electrodes. For instance, like and unlike metals may be readily joined, including some nickel alloys. It is particularly suited to metals that end to crack with ordinary welding. Copper-alloy electrodes have been used to produce overlays which are corrosion-resistant or which provide good bearing surfaces. Mr. Garriott then discussed the selection of the proper copper-base electrode for particular jobs.

A discussion of the deposition characteristics of the various copper base electrodes then followed. Mr. Garriott's concluding remarks dealt with particular applications of the phosphur bronzes, silicon bronzes and aluminum bronzes to special jobs.

Following Mr. Garriott's talk, there was an interesting and lively question-and-answer period. Mr. Garriott, who is also an amateur magician, provided a final touch to the evening with some very interesting stories and tricks.

Western Michigan

Annual Welding Conference of the Western Michigan Section with a very interesting program was held on Friday, April 21st, at Grand Rapids, Mich. Director of the Conference was Carl Van Loo, Chief Engineer of Rapids Standard Co., Inc., and Second Vice-Chairman of the Section. Registration began at 8:30 A.M. Words of Welcome were given by R. E. Kemp, Acting Chairman of the Western Michigan Section. The morning sessions had papers by Harold Lange, Sales Engineer, the National Electric Welding Machine Co., Bay City, Mich., and Cecil C. Peck, President of Cecil C. Peck Co. The afternoon sessions had papers by O. B. J. Fraser, President of the A.W.S.; Leslie McPhee, Director of Welding, Whiting Corp., and Omer Blodgett of The Lincoln Electric Co.

Banquet took place at 6:30 P.M. with special features including a sharpshooting exhibition by Corp. L. Coykendall of the Michigan State Police, and a talk by Harris Goodwin, District Sales Manager, The Bastian Blessing Co., Chicago, Ill.

Wichita

The first monthly meeting of the Kansas State College Student Chapter, Manhattan, Kan., was held at the college on the evening of March 24th. There were approximately 25 students present, together with their sponsor, William J. McClure, and their welding instructor, C. P. Ballard.

Alvah F. Dyer, Chairman of the Student Chapter, very ably presided. Other Chapter Officers present were Robt. K. Morgan, Vice-Chairman; Don R. Sheets, Secretary, and Harry Parker, Treasurer.

The program for this first meeting was furnished by the Wichita Section. The K.S.C. Student Chapter is a Division of the Wichita Section.

H. W. Beeman, Chairman of the Wichita Section, welcomed the K.S.C. Student Chapter and extended to them the Wichita Section's offer of help and full cooperation. District Vice-President Ray L. Townsend gave a brief history of the A.W.S. and explained its operational structure alone with other facts as to membership, finance, etc.

Mr. Beeman then called on the Wichita Section Secretary G. Mitchell Allen, who told of the services offered by the Wichita Section Technical Representative. He also gave information on the new *Welding Handbook*. Harry Moberly, Welding Engineer for the Coleman Co. of Wichita, told of problems encountered in welding in a large manufacturing concern. J. T. Phillips Mfg. Co., Wichita, explained just what A.W.S. has done for welding through its many committees and code work. Harvey Bates of Socony-Vacuum Oil Co., and a graduate of Kansas State College, gave an inspiring talk to the boys on their future in welding and how he arrived at his present station since leaving college. Roy W. Poe, of Tweco Products Co., gave them the "Sales Slant" that welding offers to young men who desire to make selling their life work.

All of the talks were nontechnical and from five to ten minutes in length. Following the talks Mr. Townsend presented a "History of Welding."

The April meeting was held on the 10th at the Western Iron and Foundry Co. plant. A buffet supper was served in the offices of this company. J. E. Dato, Division Service Supervisor of The Linde Air Products Co., Kansas City, Mo., gave an excellent presentation of the subject with which he is most familiar—"Advantages and Methods in Oxyacetylene Flame Cutting Practices." He held complete interest of the audience. Slides showing special oxyacetylene applications and practices were shown and enthusiastically received. A live demonstration of Powder Cutting of Stainless Steel was made by R. E. Scott of The Linde Air Products Co., Wichita. Keen interest was displayed in this demonstration and many questions followed.

Worcester

The Worcester Section held its fourth Annual Dinner Meeting and Ladies Night at the Tower House on April 26th. Eighty members and guests attended.

E. N. Adams was presented a Past-Chairman's Pin by J. L. Forand, Section Secretary.

The following officers and directors were elected: *Chairman*, C. Myron Burnett; *First Vice-Chairman*, William Walker; *Second Vice-Chairman*, Arthur W. Knight; *Treasurer*, John F. Sloan; *Secretary*, Wesley A. Proctor; *Directors* (for two years), Martin J. Conway, Iver Freeman, Donald Greenwood, Clifford H. Murray.

The entertainment, under the direction of Francis S. Harvey, consisted of a professional floor show and an impromptu amateur hour. Dancing followed.

Employment Service Bulletin

Services Available

A-604. Welding expert desires position. Experience covers a period of 20 years in the metallic-arc welding field on research, development and application problems; the development of manual and automatic welding electrodes and the design and operation of equipment for their manufacture. Extensive field service associated with arc-welding applications.

More Power to America

(*Continued from page 508*)

WELDING

Dramatizations of the latest welding cost reduction techniques, samples of various welds, a complete line of arc-welding equipment and accessories and resistance-welding control items are displayed in the Welding section of the Motor Power To America Special.

Among the scores of exhibits in this section, which occupies one-third of a car, are new industrial arc welders, improved electrodes and new manual and automatic holders for the atomic-hydrogen inert-arc welding processes.

Two of the arc welders, now in production, are 200- and 300-amp. a.-c. units designed for standard heavy duty industrial use.

Utilizing silicone insulation for the first time, these units are considerably lighter and more compact than the models they will replace. Another feature of the new welders is the incorporation of an automatic "hot start" device which facilitates striking the arc.

A new flow control for inert-arc welding with d.-c. welders, which automatically controls the flow of gas and water as the arc is struck or broken, is shown in one exhibit.

Another display includes more than 70 different types of electrodes. Of these the W52 and W2075 are recently-improved, types.

A carbon-molybdenum electrode designed for welding of low-alloy, high-tensile steels, the W52 can be applied in welding high-pressure pipings and castings where resistance to creep at high temperatures and pressures is desired.

The W2075, designed for producing a machinable weld on cast iron, consists of pure nickel-core wire and an extruded black coating that is consumed in the arc and produces little slag. It can be used in all positions on either a. c. or d. c.

A simulated "Welding Store" with realistic wall and counter displays houses virtually all of the arc-welding exhibits. One of these is a series of slide visualizations showing welding processes, applications and cost-cutting techniques.

Major exhibit panels feature the display of actual equipment—welders, heads and electrodes—for manual, automatic, inert-arc and atomic hydrogen welding.

Samples of weld beads from hard-to-weld metals such as aluminum, magnesium, steel and copper are included in the welding displays, along with a wide selection of accessories including welders' protective clothing, headgear, slag chippers, electrode holders and ground clamps.

How production can be stepped up, products improved and fabrication costs reduced through proper applications of electronic resistance-welding controls are shown in two major resistance-welding displays.

One exhibit shows five products of American industry—steel window frames, shock absorbers, axle supports, a watch and railway car frame. Each of these represents a case in which electronic control of tap resistance welding has enabled a job to be done better, faster or cheaper. In each case, a photograph of the welding operation is displayed along with actual samples of the welds.

The other resistance-welding exhibits features "slope control," a recent General Electric development which presently is helping to solve many resistance-welding problems, particularly with hard-to-weld metals such as aluminum. Through the use of this control, "tip pickup" in spot welding and "expulsion" and "splatter" in projection welding are greatly reduced because the operator is enabled to increase welding currents gradually.

WELDING RESEARCH COUNCIL

of the Engineering Foundation

**Sponsored by the American Welding Society and American Institute of Electrical Engineers
American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers
American Society of Mechanical Engineers, and Society of Naval Architects and Marine Engineers**

Supplement to The Welding Journal, June, 1950

Study of Core Wire for Electrodes

The influence of core wire on the characteristics of low-carbon steel welding electrodes. Best results are obtained with rimmed steel and sulphur content below 0.03%

by C. B. Voldrich, D. C. Martin and P. J. Rieppel

INTRODUCTION

STEEL wire which is produced for use in gas and arc welding is a special commodity which requires restrictive practices in its manufacture in order that it will give satisfactory performance during welding. Extra precautions are taken in the manufacture of the steel, in the selection of the heats of steel, in the selection and preparation of the billets and in making tests of the rods and the finished wire. The chemical composition of the steel must be closely controlled, and the wire is furnished to restricted chemical limits.

It is the consensus of the Wire Rods and Wire Committee of the American Iron and Steel Institute on the basis of knowledge now available, that many of these restrictive practices are necessary for proper control of welding wire quality. The experience has been, however, that even though welding wire of satisfactory quality can be produced by adherence to these practices, some consumers of electrodes insist on still more restrictive specifications. In order to determine whether the practices now used are too severe or not severe enough, and to obtain other information on the characteristics of welding wire, American Iron and Steel Institute authorized a research investigation at Battelle Memorial Institute on this subject, under the supervision of the Technical Committee on Welding Rods. While the broad problem involves a study of several types of wire ranging from low-carbon steel to extra high-carbon steel, and wire for both gas welding and arc welding, it was decided to begin the investigation with a study of low-carbon steel wire for metal-arc welding. The predominant tonnage is in this class, and the more important problems seem to be in the production of wire for electric arc welding.

With the project thus narrowed down, the research investigation was begun early in 1946 with the following program:

1. A study of the influence of various types of core wire on:
   - (*a*) The operating characteristics (usability) of welding electrodes.
   - (*b*) Strength, ductility, soundness of weld metals.
2. Core wire variables to be studied:
   - (*a*) Type of steel (rimmed, capped, semikilled, killed).
   - (*b*) Location of core wire in heat (ingot location, billet location).
   - (*c*) Chemical composition.
     1. Maximum permissible carbon, manganese, sulphur and phosphorus ranges.
     2. Maximum permissible residual silicon, aluminum, copper, chromium, nickel and molybdenum.
   - (*d*) Physical characteristics (structure, inclusion, core-to-rim ratio).

C. B. Voldrich, D. C. Martin and P. J. Rieppel are connected with Battelle Memorial Institute, Columbus, Ohio.

Originally presented at an annual meeting of the A.I.S.I.

3. Evaluation of the relative influence of the core wires and various types of coatings on the performance of electrodes and on weld metal properties.

4. A study of the influence of the base plate (the steel being welded) on the properties of weld metals made with low-carbon steel electrodes.

This report presents the results of the research work done during the years 1946, 1947 and 1948. The data are based on many hundreds of tests of core wires from various types of steel, and from various locations in the heat and in the ingot. Tests were made with bare wire electrodes, and with covered wires representative of three widely used classes of low-carbon steel covered electrodes. Various types of welding tests were made in all welding positions by several operators, and also with automatic welding machines.

GENERAL PROCEDURE

So far as is known, there is no single generally accepted procedure for the evaluation of the characteristics of welding wire. The published data on this subject are very meager, and not much information of a specific nature was found on core wire tests. However, sufficient information was collected, in consultations with various wire manufacturers and consumers, and with engineers and metallurgists in the welding industry, to form a basis for a testing program which is believed to be representative of general practice, and which has provided useful and significant results.

There are many variables which can affect the behavior of arc-welding electrodes. Among these are: (1) the type and formulation of the electrode coating; (2) the kind and magnitude of welding current (direct or alternating) and arc voltage; (3) the characteristics of the welding-current generator or transformer; (4) the position of welding; (5) the characteristics of the electrode core wire; (6) the characteristics of the base plate and (7) the skill of the welding operator.

Of the two variables of most immediate concern in this investigation—namely, the electrode coating and the core wire—the coating exerts the stronger influence on welding electrode behavior. This complicates the testing problem, because the influence of the core wire variables are either masked or altered by the influence of the coating. It would be convenient if the usefulness of core wire for covered electrodes could be determined by testing only bare wire; or if an experimental electrode coating could be devised which would magnify the influence of the core wire on operating characteristics. It is the practice, in some quarters, to get a preliminary rating on the applicability of a core wire for covered electrode use by an inspection of its composition, structure, and surface condition and by conducting certain bare wire welding tests. Experience has shown that this procedure is useful, within limits. For the purposes of this investigation, however, it was considered desirable to make not only the bare wire inspections and tests, but also welding tests on wires covered with various types of coatings.

Compositions

This brings up a further problem. For any given class of coating, there are numerous commercial formulations. Some of these may be identical, and others may vary considerably in the proportion and kind of ingredients used. Since the specific compositions of the commercial coatings are not known except to the electrode manufacturers, it was necessary to resort to coating formulations which are known to be representative of the various electrode classes, but which do not conform, except by accident, with the formula for any particular brand of electrodes.

During the first few months of the investigation, experiments were conducted with various coating compositions until several coatings were found which produced electrodes comparable in performance and weld metal properties with several representative commercial brands. It is possible, so far as operating characteristics are concerned, that these experimental coatings would not meet the rigorous test of field use; but it was felt that this was no disadvantage, since an electrode coating with one or more points of deficiency might bring out the influence of the core wire even more than a better coating.

Because of the large number of core wire samples which had to be studied, it was necessary to limit the classes of coating to three, which are believed to give a reasonably good representation of covered electrodes of the low-carbon steel type. The coatings used were Class E6010 (all-position, direct-current reverse polarity, cellulosic coating type), a Class E6012 (all-position, direct-current straight polarity or alternating current, rutile coating type) and a Class E6020 (downhand position, direct current or alternating current, iron oxide coating type).

The welding conditions used in the welding tests were usually the optimum for the various electrode classes. Sufficient testing was done with abnormally high and low welding currents, arc lengths, and welding speeds to make certain that no important indications would be overlooked by welding only under optimum conditions. A given series of welding tests was usually made by different welding operators to make the over-all evaluations of electrode performance independent, so far as was possible, of the operator variable.

All of the welding tests were made using direct-current welding generators. A limited number of tests was made with three different types of welding machines to determine the possible influence of generator characteristics on the operation of the electrodes.

At the start, it was thought that the base-plate variable could be eliminated, in the tests of electrode behavior, by using only one grade of high-quality killed-steel plate. However, as the project went on it became evident that the influence of the base plate could not be ignored. Consequently, a considerable amount of work was done with different types of base plates, in addition to that originally outlined on the influence of base plate on the properties of weld metals.

TEST MATERIALS

The Core Wires

The core wires used in the major part of the investigation were taken from commercial heats of steel, whose chemical compositions are given in Table 1. All of the wires were drawn to $^{3}/_{16}$ in. diameter. A detailed schedule of the samples received for tests, and chemical analyses of the wires are given in Table A-1 and A-2, Appendix A. The heat histories and mill data on billet and rod inspection and wire-drawing procedure are given in Tables A-3 and A-4.

Steel Types

There were four lots of rimmed steel wire (steels Dr, Er, Fr and Gr), one lot of shaker rimmed wire (steel Gsr), two lots of capped steel wire (steels DC and Ec) and one lot each of semikilled steel wire (Steel Xs) and killed-steel wire (Steel Zk).

During the manufacture of the rimmed steel heats D and E, three ingots in each heat were mechanically capped. These ingots (Dc and Ec) and the adjacent rimmed ingots (Dr and Er) were processed into wire for this investigation.

Likewise during the manufacture of the rimmed steel heat G, three ingots were shaker rimmed, and these, with three adjacent rimmed ingots, were processed into the wire samples Gr and Gsr.

Sampling of the Heats

For each of the nine lots of steel, wire was received from three ingots: the second or third ingot in the heat, the middle or adjacent ingot and the first or second from the last full ingot. All of the test ingots were cropped 18% at the top and 3% at the bottom, with the exception of the ingots from steels F, X and Z. The ingots from Steel F were cropped 25% at the top and 7% at the bottom. The ingots from Steel X were cropped 11% at the top and 3% at the bottom. The hot tops were removed from the Steel Z ingots and they were cropped 2% at the bottom. From each of the 27 test ingots, eight to fourteen billets were taken according to the schedule shown in Table A-1. Each test billet was processed into two 100-lb. coils of bright finish wire, which were paper wrapped in the usual manner and shipped to Battelle. Consequently, the wires available for tests consisted of a 200-lb. sample from each of 280 billets.

Eighty-one of the samples were used in the work described in this report. These represented the top, middle and bottom billet in each test ingot. It was not known, at the start, whether this would be an adequate sampling of the ingots, but it was necessary to limit the number of tests until the need for a study of the intermediate billets was demonstrated. It now appears that the top, middle and bottom samples are sufficient to give the data desired in this phase of the investigation.

Metallographic Inspection of Wires

During the first year of the investigation, a metallographic inspection was made on 27 selected samples from the 81 test billets, to obtain data on the structure, inclusion count and core-to-rim ratio. At the same time, the mill data on etch tests of billets and rods were studied. While there were significant variations in the type and incidence of inclusions in the various samples and in the core-to-rim ratios, these data have thus far not shown any significant relationship to core wire welding characteristics. Because of this, the metallographic inspections have not been extended, and will not be resumed unless the need arises. Perhaps further studies will be made in connection with the investigation of the influence of sulphur content.

TABLE 1

Chemical Composition of Wires Used in Electrode Tests

Heat	Steel Type	Symbol	Composition, Per Cent									
			Average Wire Analysis[1]					Ladle Analysis				
			C	Mn	P	S	Si	C	Mn	P	S	Si
D	Rimmed	Dr	0.09	0.40	0.011	0.032	—	0.11	0.41	0.012	0.030	0.01
	Capped	Dc	0.11	0.41	0.012	0.033	—					
E	Rimmed	Er	0.12	0.48	0.005	0.029	—	0.12	0.50	0.010	0.028	0.02
	Capped	Ec	0.12	0.49	0.005	0.030	—					
F	Rimmed	Fr	0.11	0.50	0.014	0.024	<0.01	0.13	0.50	0.017	0.024	—
G	Rimmed	Gr	0.09	0.44	0.010	0.029	<0.01	0.13	0.49	0.010	0.028	—
	Shaker rimmed	Gsr	0.09	0.45	0.009	0.030	<0.01					
X	Semikilled	Xs	0.13	0.49	0.011	0.027	0.03	0.13	0.47	0.013	0.027	0.04
Z	Killed	Zk	0.10	0.43	0.011	0.025	0.03	0.12	0.37	0.011	0.025	0.04

[1] Detailed wire analyses are given in Table A-2, Appendix A.

Surface Condition of Wire

No detailed information is available on the drawing compounds used in the processing of the wires, other than that given in Appendix A, and so far no analysis has been made of the nature of the surface films on the wires. Most of the wires were received in a satisfactory bright finish condition, but one or two lots had a somewhat dirty surface which, under some electrode wire specifications, might have been unacceptable.

The choice had to be made in the beginning to use the wires either in the as-received condition, or after the surface had been cleaned. It was decided to use the wires as received, since this would be most representative of production procedure, and since any wire cleaning operation which effectively removed the surface film might change the welding characteristics appreciably. This is definitely true, as will be shown later, for bare wire welding operation; but for covered electrodes the influences of variations in surface condition, within the normal limits, is probably negligible, except as it affects the extrusion, adherence and drying of coatings. Nevertheless, a study of the influence of surface condition on the properties of covered electrodes may be in order.

The Base Plates

The steel plates used for the welding tests were a killed steel conforming to A.S.T.M. A-201-44 Grade A firebox quality, a semikilled steel and a rimmed steel. The killed steel plate was received in $^3/_8$- and $^3/_4$-in. thicknesses (both rolled from the same heat), while the semikilled and rimmed steels were available in $^3/_8$-in. thickness only. The compositions of these materials are given in Table A-5, Appendix A.

The usual procedure in the preparation of plate specimens for welding tests was to flame cut them to the required dimensions and then to grit blast the surfaces and edges. No tests were made on sandblasted or pickled plates, or on as-received plates.

The Experimental Electrode Coatings

During the time that the core wire samples to be tested were being processed from the commercial heats, experiments were started on the formulation of suitable E6010, E6012 and E6020 coatings. In the initial tests, $^5/_{16}$-in., low-carbon rimmed-steel core wire was used. The composition of this wire was within the limits specified for the experimental wires. The initial batches of experimental coated electrodes were made using laboratory equipment. When tests of weld metal samples made with a given class of experimental electrodes indicated that the strength properties conformed with specifications for that class, a larger batch of trial electrodes was made using a commercial production line which was made available for this work by an electrode manufacturer. In the production of these larger batches of electrodes, the same coating ingredients were used as in the laboratory batches. Sufficient quantities of the various types of coating ingredients were stocked at Battelle so that no changes in material would have to be made in the future. It was a definite observation, which merely confirms production experience, that the same coating formula applied in the laboratory and on a much larger scale with factory equipment will not produce the same electrode. For this reason, all of the experimental electrodes used in the tests described in this paper were made on a relatively large scale in the electrode plant.

In addition to weld metal strength tests, the operating characteristics of the initial large batches of electrodes were compared with those of several commercial electrodes of the same class. These tests indicated that the usability of the experimental electrodes was satisfactory. The experimental coating formulas used in the preparation of all subsequent electrodes and extrusion and drying data are summarized in Table A-6 and A-7, Appendix A.

As the investigation progressed, it became evident that one of the experimental electrode types, Class E6012, did not permit the same latitude in welding conditions as the comparison commercial electrodes. However, within the optimum range of welding current and voltage, the experimental E6012 electrode is comparable to the commercial brands.

DESCRIPTION OF WELDING TESTS

To determine the usability of the experimental electrodes and the properties of weld metals made with the electrodes, the following tests were used:

1. Bead deposits
   - (*a*) Manual and automatic welding in the flat position with bare and covered electrodes, for operating characteristics.
   - (*b*) Automatic welding in the flat position with bare and covered electrodes for burn-off rates, deposition efficiency, weld metal soundness and penetration characteristics.
2. Fillet welds
   - (*a*) Manual welding in flat, horizontal, vertical and overhead positions with covered electrodes for operating characteristics.
   - (*b*) Manual (all positions) and automatic (flat position only) welding with covered electrodes for burn-off rates and deposition efficiencies.
   - (*c*) Automatic welding, vertical position welding downward with covered electrodes for surface pitting studies.
3. Single-vee groove welds
   - (*a*) Manual welding in the flat position with covered electrodes for operating characteristics, weld metal soundness, weld metal strength tests and weld metal chemical analyses.

To obtain a reliable indication of the operating characteristics of a given sample, a large number of

electrodes ranging from ten to fifty 14-in. sticks was used for each test. Welds were made with a selected experimental electrode, then with the commercial standard and so on until the test run was finished. This made possible a closer evaluation of the various factors involved in the usability studies. Where there was doubt concerning the interpretation of a weld test, duplicate tests were made by several operators.

The tests for weld-metal strength and soundness, burn-off rates and deposition efficiencies were reasonably straightforward and permitted a quantitative evaluation. In the analysis of the usability characteristics, however, it was necessary to rely largely on the judgment of the welding operators. To assist them in this work, detailed check sheets were prepared on which the operator was asked to check off each pertinent factor, rather than to simply write a statement concerning his opinion of the operating characteristics of a sample. For example, the electrode evaluation sheet required an evaluation of the following factors to the degree indicated:

Arc stability—good, moderate or poor.
Metal transfer—spray, fine globular, coarse globular.
Pool action—quiet, moderate boil, vigorous boil.
Spatter—fine, medium, coarse.
Weld surface—smooth, moderately rough, rough.

Various other factors, such as irregularity in width of bead and fillet welds, degree of undercutting and penetration and difficulty in manipulating the weld pool in various positions, were included in the evaluation. This detailed evaluation was made for each stick of electrode consumed. The information was then condensed into an over-all usability rating—"good," "fair," or "poor"—in comparison with the rating of the commercial standard.

It is realized that the above method has its drawbacks, but there is yet no well-proved technique which permits a truly quantitative determination and analysis of the many factors entering into usability. Research investigations are being conducted in several laboratories to determine the possibility of using instruments to measure at least some of the usability characteristics such as arc stability and metal transfer. The chief deficiency of the qualitative evaluation in which all the factors are ultimately lumped together in one rating is that an electrode may be rated good which is markedly deficient in some single respect. In the present tests, however, the three important factors—arc stability, metal transfer and pool action—have been given the greatest weight in the over-all analysis and a deficiency in any one of these factors is very likely to show in the over-all rating.

As part of the work on this investigation, experiments are being conducted to determine the practicability of obtaining at least a partially quantitative measurement of arc stability. Apparatus has been constructed for this work which measures arc stability by counting the short circuits occurring in the arc and measuring their duration. A complete evaluation would mean, in addition, measurement of instantaneous fluctuations in arc current and voltage, and of several other factors, and would make the method prohibitive for the present purpose. The short circuit counter is a relatively simple instrument, and once installed requires only the reading of three or four electrical counters after the burn-off of a sample of electrode. Tests are now in progress to evaluate the usefulness of this instrument for future use.

Another criterion sometimes used in the evaluation of electrode performance is the tendency toward the formation of surface porosity or pits in the weld deposit. There are several distinct factors which may induce this kind of weld defect. The composition of the base plate is known to have an effect; steels with a high sulphur content will cause not only internal porosity but surface pitting in welds made with the conventional types of mild steel electrodes. Variations in the coating composition and sometimes in the amount of moisture or combined water in the coating will influence the incidence of surface pitting. Some types of electrode coatings are much more prone to produce surface pitting than others.

Vertical fillets made in a downward direction are often used to magnify surface pitting tendencies. This welding procedure is sometimes used in the making of fillet welds in the fabrication of steel weldments, and has been recommended as an effective means of detecting differences between various types of electrodes. It was therefore used in tests of electrodes made with different types of core wires to see if the core wire, as well as the coating, could influence the formation of surface pits. The test procedure was to make a number of vertical down fillet welds in $^3/_8$-in. steel plate with each of several selected electrodes and to rate the surface pitting tendencies of the various samples in terms of the number of surface pits per inch of fillet weld.

In the initial vertical down fillet weld tests, the welding was done manually. It was found, however, that the incidence of surface pitting could be varied by the operator at will, depending on the length of the arc and the speed of welding, and that different welding operators consistently produced different amounts of pitting with the same electrode. In order to eliminate the factor of the welding operator, an apparatus was constructed to make possible the automatic deposition of the vertical down fillet welds. All of the pitting data presented in this paper were obtained from automatic fillet weld tests.

In almost all of the surface pitting tests killed steel plate was used. However, the influence of the type of base plate was also studied briefly and these tests are described in a subsequent section.

TESTS OF BARE WIRE ELECTRODES

Welding tests were made with bare wire electrodes from the top, middle, and bottom of the middle ingots of the nine steel types available. The objectives of these tests were: (1) to find out if there were any differences in the welding behavior of the four types of rimmed

steels, Dr, Er, Fr and Gr; (2) to compare the welding behavior of the rimmed and capped steels from the same heats; (3) to compare the behavior of the rimmed and capped steels with that of the semikilled and killed steels and (4) to obtain any data on operating characteristics which might be useful in later correlation with the results of covered electrode tests of the same samples.

The wires were used in the bright bare condition, which is in accordance with the practice used by some electrode manufacturers as part of their electrode evaluation procedure. As mentioned previously, it was decided to use the wires in the as-received condition, since cleaning to remove the surface films definitely effects some of the operating characteristics of the bare wire electrodes.

The operating characteristics were determined by making manual and automatic bead deposit tests and manual filler welds in various positions. The burn-off rate tests were made using flat position bead deposit tests and an automatic welding machine with a recording device for plotting the rate of burn-off during the consumption of each stick of electrode.

USABILITY AND BURN-OFF RATES

Influence of Steel Type

The data on the operating characteristics of the bare wire electrodes tested are summarized in Table B-1, Appendix B. There was no significant difference in the behavior of the four rimmed steels, the shaker rimmed steel and the two capped steels. All were rated by the operator as having a good usability, so far as bare wire is concerned. The optimum arc voltage for all of these samples was between 18 and 22 v., the arc stability varied from steady to slightly unsteady. All wires burned off with gobular metal transfer and with a moderate amount of fine spatter from the weld pool.

The operating characteristics of the semikilled and killed-steel samples Xs and Zk were much inferior to those of the rimmed and capped steel samples. It was necessary to hold a longer arc to prevent freezing of the electrode to the workpiece; the optimum arc voltage was about 24 to 26 v. for the semikilled samples and 26 to 29 v. for the killed-steel samples. The arc was very unsteady and the metal transfer was stringy or ropey and more erratic. In the killed-steel welds, there was considerable large spatter. The operators rated both of these samples as having very poor usability.

Figure 1 shows the burn-off rates for the various steel types. The average burn-off rate was substantially the same for all rimmed, capped and shaker rimmed samples, ranging from about 10 to 13 in. per minute for the welding conditions used. The exception was wire from the rimmed steel Gr, whose burn-off rates were lower than the average, about 8 1/2 to 10 in. per minute. The burn-off rates of the semikilled and killed-steel samples were significantly higher than those of the rimmed-steel wires.

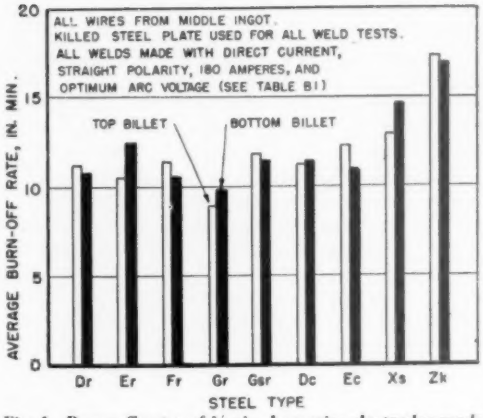

Fig. 1 Burn-off rates of 3/16-in. bare wire electrodes made from various types of steel

In general, the burn-off rates for a given core wire were reasonably consistent from electrode to electrode. However, in two of the steels, Er and Ec, there was some variation in the burn-off rate from electrode to electrode, and what may be more significant, the burn-off rate changed during the consumption of a 14-in. length of wire. These data are shown in Table 2. It is not known whether this behavior was a result of inherent properties of the wire itself, or whether variations in the surface conditions in the samples were responsible for the variation in burn-off rate.

TABLE 2

Variation in Burn-Off Rates of Four Types of 14-Inch Bare Wire Electrodes

Steel Type	Heat	Ingot Location	Billet Location	Burn-Off Rate, In./Min. Range	Burn-Off Rate, In./Min. Average
Rimmed	D	1	b	10.5 - 11.1	10.8
Rimmed	E	2	t	9.2 - 11.4	10.6
Capped	E[1]	2a	b	9.0 - 12.8	11.1
Killed	Z	2	b	16.3 - 17.5	17.0

[1] One wire of this type had a burn-off rate of 9.3 inches per minute for about 6 inches of its length, then the burn-off rate changed to 11.1 inches per minute for the remainder of the electrode.

Radiographic examination of the bead welds made during the operating characteristics and burn-off rate tests showed that all of the bare wire welds were extremely porous. No trend or relation was found between porosity and the type of wire used.

Influence of Core Wire Location

No tests were made to determine the possible influence of ingot location in the heat on the operating characteristics of the bare wire electrodes, because it was not desired to devote too much time to the bare wire tests. However, all tests were made with wire from at least the top and bottom of the middle ingots, and the

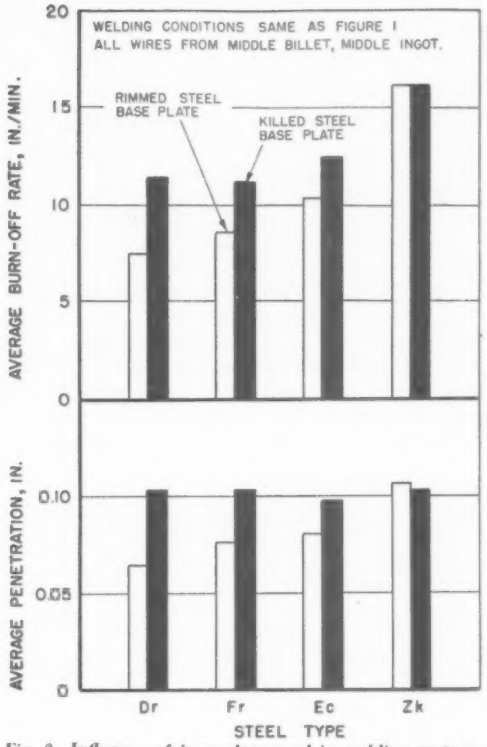

Fig. 2 Influence of base plate used in welding tests on burn-off rates and penetration characteristics of various types of bare wire electrodes

characteristics, of the different billets were studied. As shown in Fig. 1, there is no significant difference in the burn-off rate of wire from the top and bottom billets of a given ingot. This is in line with the observations that the billet position had no influence on the other operating characteristics of the bare electrodes.

Influence of Base Plate

All of the welding tests described in the two previous sections were made using killed-steel plate. In a later phase of the investigation on covered electrodes, tests were made with rimmed- and semikilled-steel base plates as well as with killed-steel base plates. At that time, some companion tests with these plates were also made using bare electrodes, to check the early findings on bare electrode burn-off rates. While there was no visible difference in the arc stability and metal transfer when various types of bare electrodes were used on killed-steel and rimmed-steel plates, there was a definite influence on burn-off rate. This is shown in the top half of Fig. 2. The rimmed- and capped-steel sample tests (Dr, Fr and Ec) showed significantly lower burn-off rates on rimmed-steel plate than on killed-steel plate. The killed-steel wire (Zk) had the same burn-off rate on rimmed-steel plate as on killed-steel plate.

Figure 2 also shows the depth of penetration of bare wire weld beads made on killed-steel and rimmed-steel plate. The rimmed- and capped-steel core wires gave greater penetration on killed-steel plate than on rimmed-steel plate. No difference in penetration was found when a killed-steel core wire was used. The reasons for this influence of base plate are not known. The variation in depth of penetration might be explained on the basis of the difference in melting points of the surfaces of the rimmed- and killed-steel plates. With the same heat input, a more shallow penetration of the rimmed-steel plate might be expected. However, the influence of the base plate on the rate at which the electrodes melt off is not explainable on the basis of the data now at hand.

The influence of the base plate on the burn-off rates of bare electrodes is believed to be a very significant factor, in so far as it affects the interpretation of electrode evaluation test data. As will be shown later, the base plate has a similar influence on the weld pitting characteristics of covered electrodes. The important point is that if burn-off rate is used in a quantitative rather than a comparative way the type of base plate used must be indicated.

Influence of Surface Condition

A few bare wire tests were made to show the influence of surface condition on operating characteristics and burn-off rate. Samples of Gr rimmed-steel wire and Zk killed-steel wire from the middle billet of the middle ingot in the heat were tested in the as-received condition, after polishing with emery cloth, after pickling in 10% sulfuric acid (uninhibited) for 5 min. and after

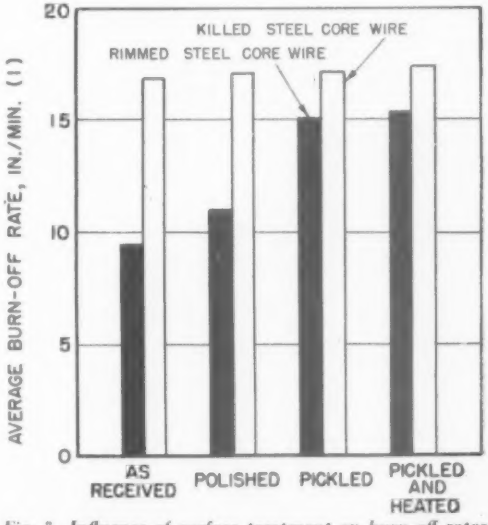

Fig. 3 Influence of surface treatment on burn-off rates of rimmed-steel and killed-steel bare wire electrodes

(1) 1/8-in. Gr., Zk wires, middle billet and ingot, d.-c. 150-amp., operating arc volt, killed plate

pickling and heating for 2 hr. at 400° F. The last-named treatment was used to drive off some of the hydrogen which the wire may have absorbed during the pickling treatment.

There was a difference in the operating characteristics of the samples with different surface treatments, and the burn-off rates were markedly affected. This is shown in Fig. 3. The rimmed steel had the lowest burn-off rate in the as-received condition. When it was polished, the average burn-off rate increased appreciably. When an as-received sample was pickled to remove the surface film, there was a very marked increase in burn-off rate from about 10 or 15 in. per minute. Pickled and heated samples showed about the same burn-off rate as the pickled samples.

The killed-steel bare wire showed no difference in burn-off rate for the different surface treatments.

When the rimmed steel wire was polished, not much change in other operating characteristics was noticed, but when it was pickled the metal transfer became coarser and the arc less stable. Neither polishing nor pickling changed the metal transfer or arc stability of the killed wires.

The few data now available on the influence of surface condition suggest that this is one of the very important factors in the production of welding quality wire, certainly for wire intended for bare-wire welding.

TESTS OF COVERED ELECTRODES

Procedure

The welding tests of core wires covered with experimental electrode coatings were conducted in much the same way as the tests of bare electrodes. A much larger number of core wire samples was used, more duplicate tests were made and the usability evaluations were based on a greater variety of tests. In most of the covered electrode welding tests, killed-steel plate was used as the base plate, but sufficient companion tests were made on semikilled steel and rimmed-steel plates to provide the necessary data for comparison. In addition to the operating characteristic tests, weld pitting and weld-metal strength tests were made on representative covered core wires.

TABLE 3

Over-All Usability Rating of Experimental Covered Electrodes Made with Core Wire from Various Types of Steel

		Summary Usability Rating[1]		
		Type of Electrode Covering		
Steel Type	Heat	E6010	E6012	E6020
Rimmed	D	Good	Poor	Good
	E	Good	Fair to good	Good
	F	Good	Fair to good	Good
	G	Fair to good	Good	Good
Shaker rimmed	G	Fair	Fair to good	Good
Capped	D	Good	Good	Good
	E	Good	Poor to Good	Good
Semikilled	X	Good	Fair to good	Good
Killed	Z	Good	Poor to good	Good

[1] See Table B-2, Appendix B, for detailed ratings according to steel type

Usability

The operating characteristics of 81 different core wires, each coated with three separate types of coating, are summarized in Tables B-2, B-3 and B-4, Appendix B. Each individual rating in the Appendix B tables is based on the observation and evaluation of numerous welding factors during the making of various kinds of weld tests, as discussed under the heading, "Description of Welding Tests." The ratings "good," "fair" and "poor" summarize information which could not conveniently be presented in this paper because of space limitations. The data from Tables B-2, B-3 and B-4 have been further condensed for the reader's convenience in Tables 3, 4 and 5, and it is to the last-named tables that the following discussion refers.

Influence of Steel Type

Table 3 indicates that for the E6010 and E6020 electrodes the core wire steel type had no appreciable influence on usability. The heat G wires, both rimmed and shaker rimmed, received a somewhat lower rating than the other E6010 wires, but nothing was found in the heat history, metallographic inspection of wires, core-to-rim ratio data or wire chemical analyses which would explain this difference in rating. On the whole, it might be stated that for E6010 or E6020 use any of the nine types of steel would make electrodes with a satisfactory usability rating.

This takes no account of core wire location in the heat. The test data for E6012 electrodes show that one of the rimmed steels, Dr, had distinctly poor operating characteristics, and a study of the detailed Tables B-2, B-3 and B-4 will show that the low rating is the result principally of the poor operating characteristics of wires from the top billet. The other rimmed and shaker rimmed and capped steels received a "fair-to-good" or "good" rating with the exception of capped steel E which, when used in E6012 electrodes, had a very erratic behavior. In this heat, the wire from the bottom of the first and middle ingots and from the top of the next to the last ingot was definitely inferior in operating characteristics and caused the over-all "poor-to-good" rating which this wire was given.

Likewise, the semikilled- and killed-steel core wires, when used in E6012 electrodes, showed a rather erratic behavior and did not receive a clean-cut "fair" or "good" rating.

Influence of Core Wire Location

Tables 4 and 5 summarize the usability ratings on the basis of the location of the core wire in the heat and in the ingot.

Table 4 shows that, considering all types of steel together, the usability rating was about the same for the first, middle and last ingots in the heat. While the E6012 electrodes gave a larger number of poor and fair

TABLE 4

Influence of Core Wire Ingot Location on Usability of Experimental Covered Electrodes[1]

Source of Electrode Core Wire	Usability Ratings
E6010 electrodes from first ingots	23 Good, 4 fair, 0 poor
" " " middle ingots	22 Good, 5 fair, 0 poor
" " " last ingots	20 Good, 7 fair, 0 poor
E6012 electrodes from first ingots	16 Good, 6 fair, 5 poor
" " " middle ingots	17 Good, 5 fair, 5 poor
" " " last ingots	18 Good, 5 fair, 4 poor

[1] See Table B-3, Appendix B, for detailed ratings according to ingot location.

ratings, this is attributed to steel type and billet location, rather than to the ingot location. A study of the detailed data in Table B-3 shows that even when the ratings are considered by individual steel type, there is no consistent trend which would suggest that the first ingot produces wire with any different characteristics than the middle or last ingot.

Table 5 presents a similar analysis by billet location for E6010 and E6012 electrodes. Here again there is no trend for the E6010 electrodes. In the E6012 electrode tests, it appears that electrodes taken from top billets are more likely to give a poorer rating than electrodes from the middle or bottom billets. Analysis of the data in Table B-4 by steel types shows that only some of the heats produced wire which had different characteristics from the top to the bottom of an ingot. The most distinct trend was observed in Steel Dr, whose three ingots all produced better wire from the bottom billets than from the top billets. A similar trend was observed in the killed steel Zk, and to a lesser degree in one or two of the other steel types. The general statement can be made that ingot location seems to have no influence on the usability characteristics of the core wires, but that wire from the top of the ingot may have some undesirable characteristics in certain instances.

The data for E6020 electrodes were not used in this analysis of the influence of core wire location, because without exception, all the E6020 electrode tests gave a good rating.

Influence of Coating Type

The three coatings used in this investigation represented types designed for different uses and had widely different operating characteristics. These differences in operating characteristics were caused chiefly by differences in arc stability, type of metal transfer and slag characteristics. The E6020 electrodes had a spray-type transfer and good arc stability; the E6010 electrodes had a globular transfer and fair arc stability; while the E6012 electrodes had the coarsest transfer and poorest arc stability.

The characteristics of the covered electrodes were controlled largely by the coating; so much so that when the same wires were covered with the different coatings, the resultant electrodes had widely different operating characteristics. Conversely, when wires which had widely different bare wire operating characteristics were covered with the E6010 coating, they had the same operating characteristics. This last was also true for different wires covered with the E6020 coating. Only when made into E6012 electrodes did the covered wires exhibit different operating characteristics.

Table 3 gives some indication of the coating influence. In general, the "poor" wires were only rated poor when covered with the E6012 coating. However, the differences which caused these "poor" ratings were not nearly so pronounced as were the differences between the rimmed-steel and killed-steel wires used bare.

TABLE 5

Influence of Core Wire Billet Location on Usability of Experimental Covered Electrodes[1]

Source of Electrode Core Wire	Usability Ratings
E6010 electrodes from top billets	22 Good, 5 fair, 0 poor
" " " middle billets	22 Good, 5 fair, 0 poor
" " " bottom billets	21 Good, 6 fair, 0 poor
E6012 electrodes from top billets	15 Good, 4 fair, 8 poor
" " " middle billets	16 Good, 8 fair, 3 poor
" " " bottom billets	20 Good, 4 fair, 3 poor

[1] See Table B-4, Appendix B, for detailed ratings according to billet location.

Influence of Base Plate

A brief study was made of the possible influence of the base plate on the operating characteristics of the experimental covered electrodes similar to that made for the bare wire electrodes. So far as could be determined from the relatively few tests made, the operating characteristics of selected rimmed, capped and killed-steel core wires covered with E6010 and E6012 coatings were not influenced by the type of base plate used (rimmed steel or killed steel).

BURN-OFF RATES

Data on the burn-off rates of selected samples of the nine types of steel from the top, middle and bottom of selected ingots are given in Table B-5, Appendix B. The data are summarized for five representative steel types in Fig. 4. The experimental E6010 electrodes all had the same burn-off rate regardless of whether the

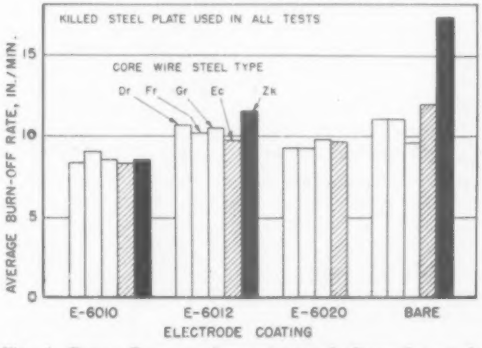

Fig. 4 Burn-off rates of experimental electrodes made with various core wires and coatings

core wire was a rimmed, capped or killed steel. This was also true for the E6020 electrodes. There was some variation in the burn-off rates of the E6012 experimental electrodes. With this coating, the rimmed steels all had approximately the same burn-off rate, the capped steel a slightly lower burn-off, and the killed steel a slightly higher burn-off rate than the rimmed steels. Additional tests would have to be made to determine the significance of these differences. It should be noted that the wide differences in the burn-off rates of the different types of bare wire were eliminated when the wires were covered with either the E6010 or E6020 coating.

The burn-off rate data in Table B-5 show that there was no significant difference in the burn-off rates of covered core wires from the top, middle and bottom of an ingot. This is true even for electrodes made with Steel D, which exhibited inferior operating characteristics for the top billet wires. Furthermore, the burn-off rate for a given electrode was the same regardless of the type of steel plate welded on.

In general, the burn-off rate was dependent on the type of coating rather than on the type of core wire used. The E6012 electrodes had the highest burn-off rates (10 to 11 in. per minute), the E6020 electrodes an intermediate burn-off rate (9 to 10 in. per minute) and the E6010 the lowest burn-off rate (8 to 9 in. per minute).

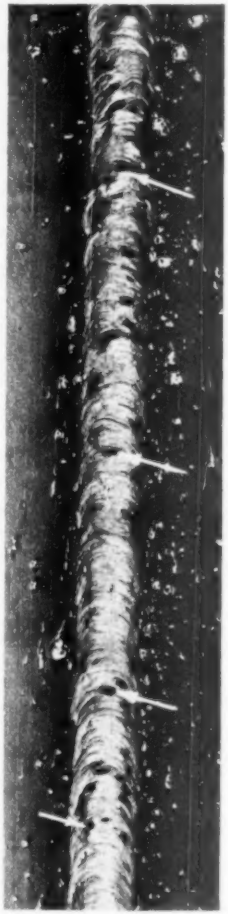

Fig. 5 Typical pitting produced by E6010 electrodes when used to make vertical down fillet welds

WELD METAL PITTING

The vertical fillet weld tests with the automatic welding machine were made with representative core wires coated with the E6010 and E6012 coatings. Tests with E6020 electrodes were not made, because these cannot be used in the vertical position.

A typical vertical down fillet weld specimen with a large number of surface pits is shown in Fig. 5. It is significant that regardless of core wire type no surface pits were produced by the E6012 electrodes, while in the E6010 electrode tests a considerable amount of pitting, which varied with the steel type and billet position, was observed. This illustrates the important influence of the coating composition on the surface pitting tendencies.

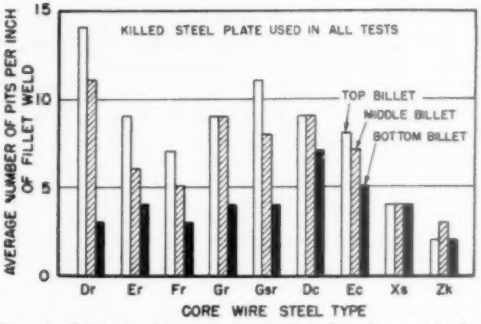

Fig. 6 Relation between core wire location and the amount of surface pitting in fillet welds made with experimental E6010 electrodes

The results of the surface pitting tests with E6010 experimental electrodes are tabulated in Table B-6 and summarized in Fig. 6, and are discussed below.

The amount of pitting varied significantly with the type of steel used as a core wire. Figure 6 shows that there was a wide variation in the amount of pitting produced by the four rimmed-steel wires. Steel Dr produced the most pitting of all the rimmed-steel wires, and Steel Fr the least. On the average, all of the rimmed and capped steel electrodes produced more pitting than the semikilled or killed-steel electrodes. The killed-steel electrodes produced the least pitting of all those tested.

Influence of Core Wire Location

The most significant trend is that in the rimmed, shaker rimmed and capped steels, wire from the top billet produced the most pitting and wire from the bottom billet the least. In the semikilled and killed steels, there was no difference in the amount of pitting produced by top, middle and bottom billet wires.

A few tests made with lightly coated bare rimmed-steel wires also showed that wire from top billets produced more pits than wire from bottom billets. These wires were coated by dipping them in liquid JM brand sodium silicate and rolling the wet wires in alpha floc (cellulose powder). They were dried by baking for 1 hr. at 250° F. This produced a coating about 0.005 in. thick which stabilized the arc enough to permit making vertical down fillet welds. This cannot be done with bare wire.

The results of the few tests made so far are given in the following table:

Heat	Steel Type	Ingot Location	Billet Location	Average Number of Pits Per In. of Fillet Weld
D	Rimmed	1	t	22
			b	2
F	Rimmed	2	t	8
			b	1

This relation between billet location and pitting will be further discussed in the section dealing with the influence of core wire sulphur content.

Influence of Base Plate

While the operating characteristics and burn-off rates of the covered electrodes were not visibly influenced by the type of base plate used, the vertical down fillet weld tests showed that the type of base plate had a distinct influence on the incidence of surface pitting in welds made with E6010 experimental electrodes.

Figure 7 shows just one example of the influence of base plate on the pitting tendencies of an E6010 electrode. The core wire in this electrode is from the first ingot of Steel Dr. The greatest amount of pitting was produced by electrodes from the top and middle billets for welds made on killed-steel plate. The bottom-billet electrodes produced much less pitting. When semikilled plate was used, the weld metal pitting was markedly reduced, and a further reduction in pitting was obtained when rimmed-steel base plate was used.

Inspection of cross sections of the vertical down fillet welds showed that the penetration into the plate on the two legs of the fillet seldom exceeded 0.03 in. This was about the same as the depth of the rim on the rimmed-steel plate. A possible explanation then of the relatively low incidence of pitting in the rimmed-steel plate is that the welds on this material were made in relatively pure metal. To check this, pitting tests were made on samples of the rimmed steel plate whose surface was planed off to a depth of about 0.050 in. to remove the rim. Fillet welds made into the exposed machined surface showed an amount of pitting approximately equal to that observed for the killed- or semikilled-steel plate.

The above observations suggest the importance, in evaluation tests of welding electrodes, of knowing the kind of plate that is being used for weld tests, and of keeping the plate variable constant so far as is possible. Another point is that when weld metal is deposited into grooved plates and surface pitting is observed, it is likely that rimmed-steel plates might give as strong a pitting indication as killed-steel plates, because in these groove welds the heart of the plate is being welded as well as the rimmed surfaces.

The core wire used in the tests of Fig. 7 produced the widest variation in pitting from one type of base plate to the other. For the other rimmed-steel and capped-steel types, there was somewhat less pitting, and the killed-steel electrode (Steel Zk) showed almost no significant difference between welds made on killed-steel, semi-killed-steel and rimmed-steel base plates.

Influence of Electrode Coating

It was mentioned previously that no pitting was produced in the vertical down fillet weld tests with experimental E6012 electrodes. The reasons for this are not fully understood. It might be mentioned here that no surface pitting was observed in any of the other tests including bead deposits, flat and horizontal and overhead fillet welds, vertical up fillet welds and groove deposits made with the E6010, E6012 and E6020 electrodes. Only in the vertical down fillet weld tests made with the E6010 electrode were these surface pits noted. It is quite possible that if a somewhat different formula had been used for the E6010 experimental electrodes, and possibly for the E6020 and E6012, that surface pitting might have been found in welds other than vertical down fillets.

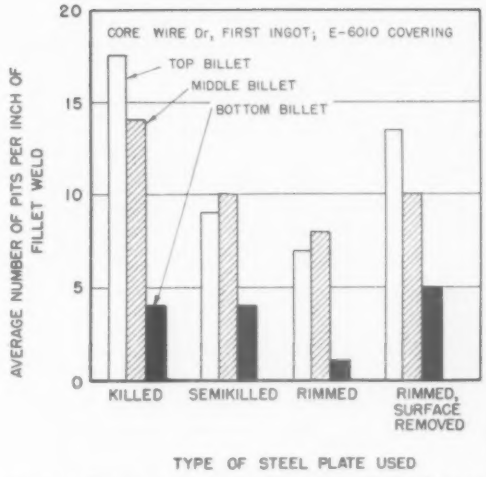

Fig. 7 Influence of type of plate used in fillet weld tests on incidence of surface pitting in fillet welds made with experimental E6010 electrode

INFLUENCE OF CORE WIRE SULPHUR CONTENT

In view of the marked relationship between surface pitting and the location of the core wire in the ingot, the surface pitting data were compared with the available information for the top, middle and bottom billets of each ingot on chemical composition, structure, core-to-rim ratio and the like. No significant relationship was found between surface pitting and core-to-rim ratio, but there was a strong relation between pitting and the core wire sulphur content. This is illustrated in the graph, Fig. 8, in which the amount of pitting is plotted against the average core wire sulphur content without regard for billet location, ingot location or heat number. However, the four general types of steel, rimmed, capped, semikilled and killed are indicated by different symbols.

It was felt that perhaps some other factor beside sulphur varied with the location of the wire in the ingot, and that the pitting should not be attributed to sulphur content alone until these other factors had been studied. The only other chemical elements for which a detailed analysis is available are carbon and manganese. Of these, carbon tends to decrease from the top to the

TABLE 6

Composition of Special Heats of Rimmed and Killed Steel Containing Various Amounts of Sulphur

Steel Type	Heat	Composition, Per Cent				
		C	Mn	P	S	Si
Rimmed[1]	AX-1	0.12	0.45	0.016	0.015	0.01
	AX-2	0.15	0.43	0.018	0.064	0.01
Silicon killed[2]	BMI-1	0.13	0.46	0.026	0.013	0.23
	BMI-2	0.12	0.47	0.027	0.026	0.25
	BMI-3	0.12	0.50	0.027	0.040	0.21
	BMI-4	0.13	0.49	0.028	0.057	0.20
Aluminum killed[2, 3]	BMI-5	0.11	0.43	0.023	0.064	0.03
	Z	0.11	0.43	0.011	0.025	0.03

[1] Heat AX made in Mill 3 pilot plant. Two ingots poured from heat. Sulphur added to AX-2 in ingot. Wire supplied from 7 billets from each ingot. Wire used in investigation taken from middle billet.

[2] All BMI heats made at Battelle; 100-lb. ingots processed into wire by Mill 5; Al-killed heat, 3 lbs. Al/ton.

[3] Core wire from commercial heat Z, Mill 5; 3 lbs. Al/ton.

bottom of the ingot, but there is no sound basis for attributing the pitting tendency to this variation in carbon content. Oxygen analyses were also made on selected samples of the top and bottom billet wires from selected rimmed and capped steel samples. It was found that there was no significant change in total oxygen content from the top to the bottom of the four ingots studied, and for the time being at least the difference in pitting cannot be attributed to oxygen. This conclusion is to a certain extent confirmed by the tests on special core wires described in a following section.

An analysis was also made of the possible influence of the distribution on sulphur from the rim to the core of the various samples on the incidence of surface pitting. It was found that the ratio of core sulphur to rim sulphur varied linearly with the nominal sulphur content and, as would be expected, no significant information was obtained from this analysis. What is needed to determine the possible influence of the rim-to-core sulphur ratio is tests on two lots of core wire; one with an average sulphur content on the high side and a high core-to-rim sulphur ratio (around 3.0), as in some or the present samples; and another lot with an average sulphur content on the low side, but also with a high core-to-rim sulphur ratio. All of the core wires now on hand which have a low average sulphur content (practically all of them from the lower billets in the ingot) have a low core-to-rim sulphur ratio.

The influence of sulphur gradient was therefore studied in another way, by making special heats of rimmed, silicon-killed, and aluminum-killed steel with varying sulphur contents, as hereinafter described.

TESTS OF CORE WIRES WITH VARYING SULPHUR CONTENT

To obtain further information on the influence of core wire sulphur content on weld metal surface pitting, a series of special heats was made with the compositions shown in Table 6. The two rimmed heats were made in a steel mill pilot plant and had substantially the same composition except for sulphur, which was 0.015% in Heat AX1 and 0.064% in Heat AX2. Four silicon killed heats were made in the Battelle laboratory, all with the same chemical composition except for sulphur, which varied from 0.013 to 0.057%. In addition, an aluminum-killed heat was made at Battelle with a sulphur content of 0.064%, for comparison with Heat Z, previously received, which had the same chemical composition but a sulphur content of 0.021%.

All of these heats were processed into $^5/_{16}$-in-diameter wire at a steel mill. The wires were then made into Types E6010 and E6012 electrodes, with the same experimental coatings as in previous tests, but using the laboratory mixing and extruding equipment rather than the commercial production line.

Up to a sulphur content of about 0.040%, the operating characteristics of the electrodes made with the special core wires were similar to those previously observed for the main group of core wires. With a sulphur content of 0.040% or more, there was violent boiling in the weld pool, for the rimmed and the killed steels alike. This boiling was observed for both E6010 and E6012 electrodes, but only in the E6010 welds was there surface pitting. The high sulphur electrodes were particularly hard to handle in the vertical and overhead positions. The burn-off rates were all similar, ranging from 8.6 to 9.0 in. per minute for the E6010 electrodes and 10.4 to 11.1 in. per minute for the E6012 electrodes with the welding conditions used.

The surface pitting tendency of the E6010 electrodes varied strikingly with the sulphur content. This is

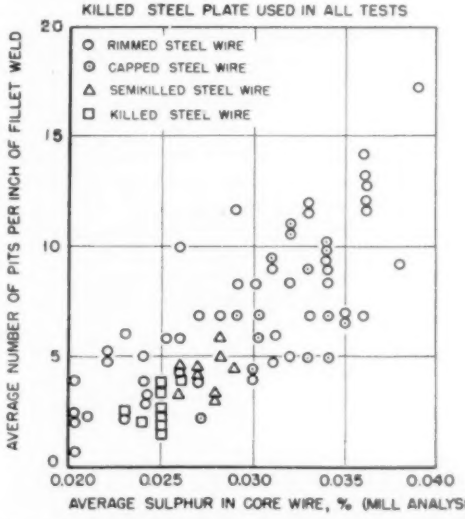

Fig. 8 Influence of core wire sulphur content on surface pitting in fillet welds made with experimental E6010 electrodes

shown in Fig. 9. The important point is that the pitting increased not only with the sulphur, as in the tests of Fig. 8, but that the uniformly distributed sulphur in the aluminum-killed and silicon-killed steels had the same effect as a comparable amount of sulphur in the rimmed wires, in which there was an increase in sulphur from the rim (0.020%) to the core (0.087%).

The data of Fig. 9 indicate that the variation in surface pitting is a function of the average sulphur content rather than of the sulphur gradient. Another indication is that the distribution of the oxygen content or the nature of the oxygen in the samples has no significant influence on the surface pitting, since both the killed steels and the rimmed steels produced about the same amount of pitting for a given average sulphur content.

WELD METAL STRENGTH TESTS

One of the principal objectives of this investigation was to evaluate the influence of electrodes made with various types of core wire and of the base plate on the quality and strength of weld metals. Experiments were therefore conducted with selected E6010, E6012 and E6020 electrodes made with core wires representing the the top, middle and bottom billets of two rimmed steels, one capped steel and one killed steel. Killed-steel and rimmed-steel base plates were used.

All weld metal specimens for static tension tests were machined from butt welded plates of the killed and rimmed steels. The joint design was a single-vee, 45° groove with $^1/_2$ in. root opening, and a $^3/_8$-in. thick backup bar of the same steel type as the main plates.

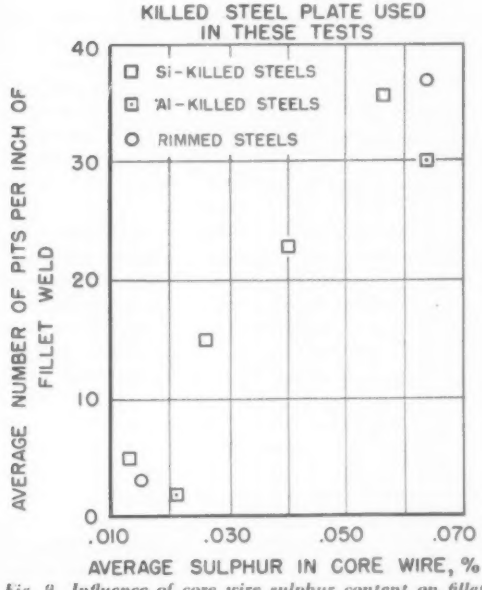

Fig. 9 Influence of core wire sulphur content on fillet weld surface pitting produced by experimental E6010 electrodes made with special core wire

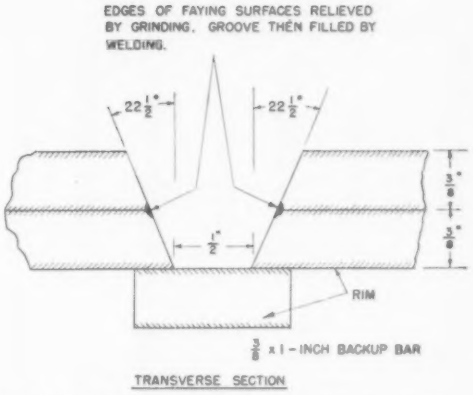

Fig. 10 Detail of weld joint for tension tests of welds in rimmed-steel plate

The main plates were $^3/_4$ in. thick for the killed steel. For the rimmed steels, two $^3/_8$-in. plates were placed together and beveled and welded, prior to the deposition of the main body of weld, as shown in Fig. 10.

All tests were on as-welded specimens (no stress relief or similar heat treatment) at room temperature. Most of the tension tests were made about 2 weeks after welding. However, some of the specimens were cut from plates which had been welded about 2 yr. previously (for operating characteristics and weld metal soundness tests) and were being held for possible use in strength tests. No significant change in ductility or yield strength was evident because of the difference in age before testing.

The strength data are given in Tables C-1 through C-6, Appendix C, and the chemical compositions of selected samples machined from broken tension specimens are shown in Table C-7.

The data show that there was no difference in the strength properties of weld metals made with electrodes from different portions of an ingot, nor any difference in the strength properties of welds made with electrodes from the four different types of steels tested. Furthermore, the strength of welds made on killed-steel plates was the same as that of companion welds on rimmed-steel plates, for any given electrode.

Effect of Coating Change

The only significant change in strength and ductility came with a change in the type of electrode coating. This is illustrated in the graphs, Fig. 11. The welds made with the E6012 electrodes had the highest yield and tensile strengths with the lowest elongation and reduction in area. The welds made with E6010 and E6020 electrodes had comparable yield and tensile strengths and elongation, but the reduction in area of the E6020 welds was somewhat greater.

The compositions of E6010 weld metals deposited by various experimental electrodes are given in Table

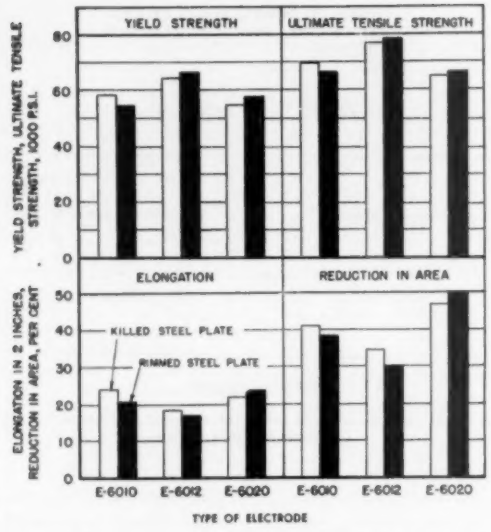

Fig. 11 Comparison of strength properties of weld metals deposited in killed-steel and rimmed-steel base plate with various experimental electrodes

C-7, Appendix C. This table shows that all of the core wires produced weld metal of about the same chemical composition. E6012 and E6020 weld-metal analyses were not made because the strength test results did not indicate that there was any difference between the deposits of various electrodes of a given type.

All of the butt-welded plates prepared for strength tests were radiographed before machining. There was very little weld-metal porosity in any of the welds, perhaps a little more in the E6012 welds than in the others. Even in the E6012 welds there was not enough porosity to establish any relation between core-wire type or base-plate type and porosity.

DISCUSSION OF RESULTS

In the over-all analyses of the tests described above, it is necessary to consider the bare wire data and the covered electrode data separately, because of the difference in the indications for the two types of electrodes. One of the objectives of the work was to find out if differences in the welding behavior of bare electrodes could be detected when the wires were coated with various classes of electrode coating; this would facilitate the evaluation of wire intended for use in covered electrodes. However, for the core wires submitted for testing, there was no welding factor which varied in the same way in both the bare and the covered electrodes, and it is therefore necessary to consider the bare wire and covered electrodes as separate problems.

The above remarks are based, to be sure, on a program which entailed necessarily limited numbers of tests, in comparison with what is done in electrode production, where the size of a wire sample is measured in thousands of pounds and where a greater number of heats of the same type of steel are processed, with perhaps an occasional "off-heat" which stands out from the others in some electrode behavior respect. On the other hand, it will be remembered that the cropping of the test ingots was with one exception much smaller than that used in the production of wire for electrode manufacturers. In the latter case, the yield from rimmed steel heats is frequently as low as 55%. This means that the test wires (yield 68 to 80%) represented a much broader cross section of the six heats studied, and the test samples could well include variables which would not ordinarily be found in wire supplied for actual production use.

Bare Electrode Tests

The welding tests of bare electrodes indicated that wire from all portions of the four rimmed-steel heats, the shaker rimmed heat and the two capped-steel heats had comparable usability characteristics, burn-off rates and weld-metal soundness. Only the semikilled- and killed-steel wire had definitely inferior operating characteristics.

When the surface condition of the bare wires was altered from the as-received condition, marked changes in the burn-off rates were observed. The effect of the surface treatment on operating characteristics was also studied by making the usual welding operator evaluation tests, but bare electrodes at best operate so poorly in comparison with covered electrodes that it is quite difficult to obtain a satisfactory rating except on the basis of burn-off rate, metal transfer and spatter loss. In the present tests of rimmed steel wires with different surfaces, the metal transfer became coarser when the wire was pickled and consequently might be rated as having poorer usability.

The burn-off rates of representative bare electrodes were markedly affected by the type of base plate used. The fundamental reasons for this are not understood, but the observation is important at least as it is related to the techniques used in the evaluation of the usefulness of different heats of bare wire.

In general, none of the indications from the bare wire tests was useful in the subsequent analysis of the performance of covered electrodes. It has been suggested that perhaps the reason for this is that all of the available samples were representative of good heats; and that if an "off heat" or an "off ingot" had been included, some of the bare-wire indications would have been stronger or different, or would have persisted in the coated electrode tests. This, however, is a matter of conjecture. It is hoped that samples of questionable or rejected wire will become available for check tests. It is well to state here that such wire is hard to obtain; in the past three years, only two small samples of wire have been received which were definitely rated by either the manufacturer or consumer as below standard. Unfortunately, the background information on the heat history of these samples and on the welding tech-

niques used to evaluate them as substandard was of such an unspecific nature that significant comparison tests between these small samples and the large samples in the main body of tests could not be made.

Covered Electrode Tests

The first point that comes up in the analysis of the covered-electrode tests is that the electrode coating has a much greater influence on electrode characteristics than the core wire. This of course does not apply to core wires with extreme chemical compositions, high sulphur for example. The stronger influence of the coating may be illustrated by the following three examples. First: when a rimmed steel and a killed-steel core wire are coated with certain types of coatings such as the E6010, the widely divergent characteristics of the bare wires are brought together, and the two electrodes have virtually the same operating characteristics, burn-off rates and weld-metal properties. This is also true when the E6020 coating is used. Second: a core wire with sulphur on the high side (say 0.040%), and covered with an E6010 coating, will produce a considerable amount of surface pitting under certain welding conditions; but this pitting can be totally eliminated for the same core wire by using another type of coating such as E6012, or perhaps even by modifying the original E6010 composition. Third: core wires of different steel types but with the same chemical composition will produce weld metal of the same properties for a given coating type; but if covered with different coatings, the weld-metal properties are different.

The conclusion may be drawn that some of the deficiencies which have been attributed to core wire characteristics are really due to coating characteristics and should be corrected in the coating.

However, when E6012 coatings were used, the operating characteristics tests showed some indications of differences between steels. The semikilled- and killed-steel core wires were not so good, and one of the rimmed steels, Dr, was given a somewhat lower rating than the other rimmed steels. In addition, the E6012 operating characteristics tests indicated that wires from top billets were prone to give less satisfactory results than wires from the middle or bottom billets. It should be remembered that had these ingots been cropped in the usual manner, the top billet wire would have been discarded and possibly the observed differences would not have been so apparent. Nevertheless, the usability tests showed that for certain types of coating the electrode behavior is sometimes affected by the core-wire properties.

One of the objectives of the investigation was to determine if capped steels and rimmed steels of the same composition had the same operating characteristics. The available test data indicate that this is so, and that capped steel can be used in the production of mild-steel covered electrodes. In this connection, a comment is needed on the significance of the ratio of core-to-rim area which is sometimes used in the grading of rods and wire for electrode production. Nothing in the present investigation has shown that this numerical ratio is of importance in the evaluation of electrode wire.

The strongest indications of differences in the core wires were obtained from the fillet weld pitting tests. As mentioned previously, it is difficult to establish a good relationship between the pitting test indications and the usability ratings. For example, the E6010 electrodes gave uniformly good usability ratings but produced wide differences in surface pitting. On the other hand, the E6012 electrodes, which showed significant trends in usability, produced no surface pitting. From this standpoint, the pitting test data might be considered useful only when analyzed in combination with the results of other types of tests. Nevertheless, the pitting tests provided very useful clues to the differences between wires from the top and bottom of an ingot, and led to the more detailed studies of the influence of core wire sulphur on electrode characteristics.

The data indicate that the surface pitting tendency increases rapidly with increase in the average sulphur content of the core wire. This is true for all types of steels—rimmed, capped, semikilled and killed. A sulphur content within the limits normally specified (0.035% maximum sulphur) had no noticeable effect on the usability characteristics or weld metal properties, but there was a distinct increase in the amount of surface pitting (for one type of coating—E6010). Consequently, if surface pitting is being used in production as a measure of the suitability of wire for electrodes, a better rating should be obtained if the sulphur content is on the low side. This means either the use of sufficient cropping to remove the material from the top of the ingot which tends to be high in sulphur, or to use a steelmaking practice in which the segregation of sulphur toward the top of the ingot is minimized. The present tests indicate that the segregation of sulphur toward the center of the ingot is not important so long as the average sulphur content is controlled.

When the sulphur content of the core wire is more than about 0.040%, the operating characteristics of the electrode begin to deteriorate. This is noted chiefly in an increased boiling of the weld pool. For sulphur contents less than 0.040%, however, the present tests showed no visible difference in the usability characteristics. Therefore, it is believed that considerable additional study of the relation between surface pitting and other operating characteristics is necessary before the pitting test in one form or another can be safely used for grading of core wires.

The weld-metal strength tests showed that the type of core wire, within the limits of the compositions studied, had no influence on the strength, ductility, or soundness of the weld metals.

No study has been made of the possible influence on core wire characteristics of variations in carbon, manganese and phosphorus contents, and excessive amounts of residual elements such as silicon, aluminum, chromium, copper, nickel and molybdenum. The principal

reason is that all of the samples thus far available have had reasonably similar compositions, and it has not been possible to discern the possible influences of these elements among the much stronger influences of the electrode coating, the sulphur in the core wire, and the base plate.

It is possible that, if the sulphur variable is found to be the important one in the manufacture of low-carbon steel core wire, the need for studies of the other elements diminishes. However, if the residuals in the low-carbon grade wires continue to increase, perhaps some attention should be given to an investigation of their effect on welding characteristics. This is probably more important in the manufacture of steel wire for covered electrodes of the lime-titania, controlled hydrogen type. For example, it is understood that in some of the higher strength electrodes of this type, residual elements such as tin and copper in the core wire are apt to make the weld metal susceptible to cracking during welding.

Another factor which definitely deserves additional study is the influence of the surface condition of core wires on the operating characteristics of bare and covered electrodes. In the research work so far conducted, this factor has been studied only slightly, but already some indications of its importance, particularly in bare wire welding, have been noted.

SUMMARY

The findings may be summarized with due consideration for the limitations in the varieties of core-wire samples available, the number and types of tests conducted, and the limited number of coatings studied, as follows:

1. When covered with the E6010 or E6020 experimental coatings, all of the core wires, including the nine steel types and wires from different locations in the heat and ingot, made satisfactory welding electrodes.

2. When the E6012 coating was used, some of the core wire samples exhibited deficiencies in certain welding characteristics. The steel from Heat D, which on the whole had a higher sulphur content than the other steels, produced less satisfactory electrodes than the other steels. For this and some of the other heats, wire from the tops of the ingots produced less satisfactory E6012 electrodes than wire from the middle or bottom of the ingots.

3. The semikilled- and killed-steel core wires did not make good electrodes when coated with the E6012 coating.

4. The pairs of rimmed and capped steel core wires from the same heats produced wire of comparable welding characteristics.

5. The core-to-rim area ratio, which is sometimes used in an appraisal of the quality of welding wire, could not be related to any of the welding characteristics of the experimental electrodes.

6. The most important single core wire variable which affected the operating characteristics of covered electrodes was the average sulphur content. Sulphur contents of more than 0.040% caused the electrodes to have deficient operating characteristics and severe weld pitting tendencies. Sulphur contents of between 0.030 and 0.040% produced electrodes which had severe weld pitting tendencies, but acceptable operating characteristics. The best results were obtained with core wires which had an average sulphur content of about 0.030% or below.

7. The mechanical properties of weld metals deposited with the experimental electrodes were determined by the type of coating used. The type of steel in the core wire or in the base plate and the location of the core wire in the heat had no discernible influence on weld-metal strength or ductility.

8. None of the covered electrodes produced welds with excessive internal porosity, regardless of the core wire steel type, location of the core wire sample or the coating used. In general, it might be said that there was practically no porosity in any of the groove or fillet welds, with the exception of the vertical down fillet welds which were made under rather abnormal welding conditions.

9. The surface condition of the core wire has an important influence on the characteristics of bare-wire electrodes; its influence on the characteristics of covered electrodes has not been studied and is not known.

10. In general, the operating characteristics of the test electrodes were affected in greater degree by the type of coating used than by the characteristics of the core wire. The exception is core wire with an abnormally high sulphur content in which case the core wire exerted a somewhat stronger influence on welding characteristics.

11. On the basis of the limited number of bare-wire tests conducted, it is felt that bare wire electrode tests do not give an adequate indication of the usefulness of a core wire for covered electrode use. It is possible, however, that a study of the pitting characteristics of fillet welds made with lightly coated electrodes would provide useful advance information on the influence of core wire sulphur on welding characteristics.

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APPENDIX A

TABLE A-1

Wire Samples Received for Tests

Heat[1]	Steel Type	Ingot Locations[2]	Billet Numbers[3]
D	Rimmed	t	1, 3, 5, 7, 9, 11, 13, 15, 17, 19
		2	1, 3, 5, 7, 9, 11, 13, 15, 17, 19
		b	1, 3, 5, 7, 9, 11, 13, 15, 17, 19
D	Capped	1a	1, 3, 5, 7, 9, 11, 13, 15, 17, 19
		2a	1, 3, 5, 7, 9, 11, 13, 15, 17, 19
		3a	1, 3, 5, 7, 9, 11, 13, 15, 17, 19
E	Rimmed	t	1, 3, 5, 7, 9, 11, 13, 15, 16
		2	1, 3, 5, 7, 9, 11, 15, 24
		b	1, 3, 5, 7, 9, 11, 13, 15
E	Capped	1a	1, 3, 5, 7, 9, 11, 13, 15, 16
		2a	1, 3, 5, 7, 9, 11, 15, 15, 16
		3a	1, 3, 5, 7, 9, 11, 13, 15, 16
F	Rimmed	t	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 20
		2	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21
		b	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 20
G	Rimmed	t	1, 3, 5, 7, 9, 11, 13, 15, 17, 19
		2	1, 3, 5, 7, 9, 11, 13, 15, 17, 18
		b	1, 3, 5, 7, 9, 11, 13, 15, 17, 19
G	Shaker rimmed	1a	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 20
		2a	1, 3, 5, 7, 9, 11, 13, 15, 17, 18
		3a	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 20
X	Semi-killed	1[4]	3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 22
		2	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 22
		b	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 22
Z	Killed	t	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23
		2	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23
		b	1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 26

[1] Source of heats
Mill 1: Heat D (rimmed and capped ingots from same heat)
Mill 2: Heat E ( )
Mill 3: Heat F
Mill 4: Heat G (rimmed and shaker rimmed ingots from same heat)
Mill 5: Heats X and Z

[2] Ingot location
t: Second or third ingot
2: Middle or adjacent ingot
b: First or second from last ingot
1a, 2a, 3a: Capped or shaker rimmed ingots adjacent to rimmed ingots 1, 2, and 3 in Heats D, E, and G.

[3] Billet location
Billets taken starting with the first billet under top crop (No. 1) and every odd-numbered billet, including the bottom billet whether odd or even numbered. The underlined numbers indicate the billets used in the experiments described in this report. These billets represent the top, middle, and bottom of each ingot, and are denoted in the report by the letters "t", "m", and "b".

[4] Billet 1 lost by cobbling in rod mill; Billet 3 used as top billet instead.

TABLE A-2

Chemical Composition and Core Area Ratios of Wire from the Top, Middle, and Bottom Billets of the Test Ingots

Heat	Steel Type	Ingot Location	Billet Location	Composition, Per Cent C	Mn	P	S	Si	Core Area, Per Cent of Total Area[1]
D	Rimmed	1	t	0.10	0.42	0.012	0.039	—	43
			m	0.10	0.42	0.012	0.035	—	43
			b	0.08	0.40	0.010	0.024	—	0
		2	t	0.10	0.41	0.012	0.036	—	41
			m	0.10	0.40	0.010	0.031	—	40
			b	0.07	0.39	0.008	0.024	—	0
		5	t	0.10	0.41	0.012	0.036	—	43
			m	0.10	0.40	0.010	0.034	—	41
			b	0.07	0.39	0.010	0.030	—	0
D	Capped	1a	t	0.11	0.45	0.012	0.034	—	88
			m	0.11	0.45	0.012	0.032	—	88
			b	0.10	0.42	0.011	0.030	—	0
		2a	t	0.11	0.42	0.012	0.035	—	78
			m	0.11	0.42	0.011	0.033	—	85
			b	0.10	0.41	0.011	0.031	—	88
		3a	t	0.11	0.40	0.013	0.035	—	79
			m	0.11	0.40	0.013	0.034	—	87
			b	0.10	0.39	0.012	0.032	—	87
F	Rimmed	1	t	0.13	0.55	0.006	0.034	—	48
			m	0.12	0.53	0.005	0.031	—	48
			b	0.10	0.52	0.005	0.020	—	48
		2	t	0.13	0.52	0.006	0.034	—	46
			m	0.12	0.51	0.004	0.029	—	46
			b	0.10	0.50	0.004	0.023	—	46
		3	t	0.13	0.49	0.006	0.035	—	45
			m	0.11	0.46	0.005	0.031	—	45
			b	0.10	0.45	0.005	0.024	—	45
F	Capped	1a	t	0.13	0.55	0.007	0.035	—	74
			m	0.13	0.55	0.006	0.030	—	74
			b	0.10	0.53	0.006	0.028	—	74
		2a	t	0.13	0.55	0.006	0.032	—	75
			m	0.13	0.52	0.004	0.029	—	75
			b	0.10	0.50	0.004	0.025	—	75
		3a	t	0.13	0.48	0.006	0.034	—	74
			m	0.12	0.46	0.005	0.030	—	74
			b	0.10	0.44	0.004	0.027	—	74
F	Rimmed	1	t	0.11	0.47	0.016	0.027	—	48
			m	0.10	0.47	0.014	0.026	0.004	44
			b	0.09	0.45	0.014	0.017	0.003	55
		2	t	0.11	0.51	0.015	0.027	—	41
			m	0.12	0.50	0.015	0.024	0.004	40
			b	0.09	0.50	0.012	0.021	—	41
		5	t	0.15	0.54	0.016	0.026	—	50
			m	0.11	0.55	0.015	0.025	0.005	50
			b	0.09	0.52	0.014	0.020	—	54
G	Rimmed	1	t	0.10	0.48	0.010	0.033	0.004	51
			m	0.10	0.46	0.009	0.028	—	51
			b	0.10	0.45	0.009	0.025	0.004	5
		2	t	0.09	0.46	0.007	0.036	0.003	43
			m	0.09	0.45	0.011	0.029	—	45
			b	0.07	0.45	0.011	0.021	0.003	45
		5	t	0.09	0.45	0.009	0.038	0.003	38
			m	0.08	0.44	0.012	0.030	—	39
			b	0.08	0.45	0.012	0.021	—	57

[1] Calculated from measurements made on deep etch specimens.

TABLE A-2 (Continued)

Heat	Steel Type	Ingot Location	Billet Location	Composition, Per Cent C	Mn	P	S	Si	Core Area, Per Cent of Total Area[1]
G	Shaker rimmed	1a	t	0.10	0.46	0.009	0.035	0.005	58
			m	0.09	0.46	0.007	0.032	—	49
			b	0.09	0.46	0.007	0.026	—	58
		2a	t	0.10	0.47	0.010	0.036	0.005	45
			m	0.09	0.46	0.010	0.033	—	58
			b	0.08	0.45	0.009	0.021	0.005	58
		3a	t	0.10	0.45	0.009	0.036	0.005	45
			m	0.09	0.44	0.009	0.032	—	40
			b	0.08	0.42	0.008	0.022	0.005	0
X	Semi-killed	1	t	0.15	0.50	0.010	0.028	0.050	—
			m	0.14	0.51	0.010	0.028	0.050	—
			b	0.13	0.49	0.010	0.026	0.050	—
		2	t	0.14	0.49	0.011	0.028	0.050	—
			m	0.13	0.49	0.011	0.029	0.050	—
			b	0.13	0.49	0.011	0.026	0.050	—
		5	t	0.13	0.47	0.011	0.028	0.050	—
			m	0.13	0.49	0.011	0.027	0.060	—
			b	0.13	0.49	0.011	0.027	0.060	—
Z	Killed	1	t	0.11	0.42	0.010	0.025	0.050	—
			m	0.10	0.45	0.011	0.025	0.050	—
			b	0.10	0.45	0.011	0.026	0.050	—
		2	t	0.11	0.41	0.011	0.025	0.050	—
			m	0.09	0.45	0.011	0.025	0.040	—
			b	0.09	0.42	0.011	0.024	0.030	—
		5	t	0.10	0.58	0.010	0.025	0.020	—
			m	0.10	0.58	0.010	0.025	0.030	—
			b	0.09	0.59	0.010	0.025	0.050	—

[1] Calculated from measurements made on deep etch specimens.

TABLE A-3

Steel Making Data for Heats Used in Investigation

	Heat D	E	F	G	X	Z
Charge, lbs						
Scrap	175,000	72,600	5,000	120,000	103,700	119,750
Hot metal	152,600	161,300	312,600[1]	195,000	167,000	151,000
Limestone	25,000	13,400	8,000	18,000	26,000	26,000
Ore	—	50,500	7,500	32,000	24,600	32,900
Working additions, lbs						
Burnt lime	1,500	1,100	9,600	—	—	—
Ore	16,000	10,700	—	5,000	—	—
Fluorspar	500	—	—	—	600	—
Lime	—	—	—	2,000	—	—
Ferrosilicon (50%)	—	—	—	—	—	500
Dolomite	—	—	—	—	9,000	5,400
Time in furnace, hrs.	11	11	4	10½	11¼	13¼
Ladle additions, lbs						
Ferromanganese (80%)	1,000	1,600	2,200	1,800	3,000[2]	1,600
Aluminum	50	—	—	—	95	420
Ferrosilicon	—	—	—	—	550	—
Coal	—	—	—	180	—	—
Ferrotitanium	—	—	300	—	—	—
Mold size, in	22 x 24	22 x 24	22 x 24	25 x 25	22 x 25	22 x 25
Mold addition, oz						
Sodium fluoride	4	(3)	3	—	—	—
Aluminum	—	1½	—	(4)	5	—

[1] 282,000 lbs. of converter metal.
[2] 1500 lbs. of 80 per cent ferromanganese, 1500 lbs. of 37 per cent.
[3] 70 oz. sodium fluoride in rimmed steel ingots, 4 oz. in capped steel ingots.
[4] 4 oz. aluminum on ingot Gt 1.

TABLE A-4

Rolling and Wire Drawing Data for Wires Used in Investigation

	Heat D	E	F	G	X	Z
Cropping, Per Cent						
Top	18	18	25	18	11	(1)
Bottom	3	3	7	3	3	3
Billet size, in	1-13/16	2	15/16	1⅞	—	—
Rod size, in.	—	¼	—	15/64	—	—
Number of drafts from rod	2	2	2	2	2	2
Lubricant on final draft	Grease	Grease	Grease[1]	Dry	Grease[1]	Grease[1]

[1] Hot topped ingot, not cropped below hot top.
[2] Lime dipped before drawing.

TABLE A-5

Composition of Steel Plates Used in Investigation

Steel Type	Plate Thickness, In.	Composition, Per Cent C	Mn	P	S	Si	Al
Killed	⅛, ¾[1]	0.14	0.52	0.014	0.028	0.28	<0.01
Semikilled	⅛	0.21	0.55	0.020	0.038	0.08	<0.01
Rimmed	⅜	0.21	0.50	0.014	0.035	0.01	<0.01

[1] Both thicknesses rolled from one heat of ASTM A201-48 Grade A firebox-quality steel plate.

TABLE A-6

Compositions of Experimental Electrode Coatings

Ingredient	Grade or Supplier	Amount in Coating Mixture, Per Cent by Weight E6010 Type	E6012 Type	E6020 Type
Cellulose	Brown & Co. Alpha Floc "B", -40 mesh	21.0	4.0	2.6
Asbestos	Johns Manville 7R05	10.5	—	6.9
Titanium dioxide	Titanium Mfg. Co., Titanox A	10.5	—	—
High-carbon ferro-manganese	Electro Metallurgical Co., -100 mesh	5.3	8.0	10.3
Calcium carbonate	Foote Mineral, 48 x 158 Calgran	—	3.0	2.6
Feldspar	Consolidated Feldspar, Derry	—	10.0	21.6
Rutile	American Rutile Co., -200 mesh	—	39.0	8.6
Talc	Kraft Chemical Co., Soapstone Talc, -200 mesh	—	10.0	—
Dextrin	Kraft Chemical Co., Canary Dextrin	—	1.0	—
Silica	Whitehead Bros. Co., No. 200 Silica	—	—	2.6
Magnetite	Foote Mineral, -80 mesh	—	—	6.9
Manganese dioxide	Technical	—	—	2.6
Sodium silicate	Grasselli Chemical Co., JM Brand (liquid)	52.7	25.0	35.3

TABLE A-7

Extrusion and Drying of Experimental Electrodes

	Electrode Type E6010	E6012	E6020
Mixing time, mins.			
Dry	10	10	10
Wet	71	26	63
Extrusion pressure, psi.	6200-6800	7800-8400	4600-5000
Die size	0.242	0.227	0.267
Maximum eccentricity, in.	0.001	0.002	0.003
Drying[1]			
Temperature, F.			
First pass	225	180	180
Second pass	225	180	180
Third pass	275	245	245
Fourth pass	275	245	245
Fifth pass	325	345	345
Time, mins.			
First pass	5	4½	4½
Second pass	5	4½	4½
Third pass	5	4½	4½
Fourth pass	7½	5¼	5¼
Fifth pass	9	5¼	5¼
Finished diameter, in.	0.232	0.223	0.263

[1] Drying was done in a five-pass continuous flow oven.

APPENDIX B

TABLE B-1

Operating Characteristics of Bare Wire Electrodes

Heat	Steel Type	Billet Location in Ingot[1]	Optimum Arc Voltage[2]	Arc Characteristics	Metal Transfer	Spatter	Operators Usability Rating
D	Rimmed	Top (t)	18-20	Slightly unsteady	Globular	Moderately fine	Good
		Middle (m)	18-20	Steady	Globular	Moderately fine	Good
		Bottom (b)	19-21	Steady	Globular	Moderately fine	Good
E	Rimmed	t	18-20	Slightly unsteady	Globular	Moderately fine	Good
		b	20-22	Slightly unsteady	Globular	Moderately fine	Good
F	Rimmed	t	19-22	Steady	Globular	Moderately fine	Good
		m	19-21	Steady	Globular	Moderately fine	Good
		b	18-21	Slightly unsteady	Globular	Moderately fine	Good
G	Rimmed	t	19-21	Steady	Globular	Moderately fine	Good
		b	19-21	Steady	Globular	Moderately fine	Good
G	Shaker rimmed	t	19-21	Steady	Globular	Moderately fine	Good
		b	19-21	Steady	Globular	Moderately fine	Good
D	Capped	t	19-22	Steady	Globular	Moderately fine	Good
		b	19-21	Slightly unsteady	Globular	Moderately fine	Good
E	Capped	t	19-22	Slightly unsteady	Globular	Moderately fine	Good
		m	19-21	Slightly unsteady	Globular	Moderately fine	Good
		b	19-21	Steady	Globular	Moderately fine	Good
X	Semikilled	t	24-26	Unsteady	Mixed globular and stringy	Moderately fine	Poor
		b	24-26	Unsteady	Mixed globular and stringy	Moderately fine	Poor
Z	Killed	t	26-29	Very unsteady	Stringy	Large	Very poor
		m	26-29	Very unsteady	Stringy	Large	Very Poor
		b	26-29	Very unsteady	Stringy	Large	Very Poor

[1] All wire from the middle ingot in the heat.
[2] All bead welds made manually, direct current straight polarity, 180 amperes, arc voltages as indicated.

TABLE B-2

Usability Rating of Covered Experimental Electrodes Made with Core Wires from Various Steels

Steel Type	Heat	Usability Rating[1] Ingot 1 t	m	b	Ingot 2 t	m	b	Ingot 3 t	m	b	Rating Count Poor	Fair	Good	Summary Usability Rating
E6010 ELECTRODES														
Rimmed	D	G	G	G	G	G	G	G	G	G	0	0	9	Good
Rimmed	E	G	F	G	G	G	G	G	G	G	0	1	8	Good
Rimmed	F	G	F	G	G	G	G	G	G	G	0	1	8	Good
Rimmed	G	F	G	G	G	G	F	F	G	G	0	4	5	Fair to good
Shaker rimmed	G	F	G	G	F	F	F	F	F	F	0	6	3	Fair
Capped	D	G	G	F	G	G	F	G	G	G	0	2	7	Good
Capped	E	G	G	G	G	G	G	G	F	F	0	2	7	Good
Semikilled	X	G	G	G	G	G	G	G	G	G	0	0	9	Good
Killed	Z	G	G	G	G	G	G	G	G	G	0	0	9	Good
E6012 ELECTRODES														
Rimmed	D	P	P	P	P	F	G	P	P	G	6	1	2	Poor
Rimmed	E	G	G	G	G	G	F	P	F	F	1	5	3	Fair to good
Rimmed	F	G	G	F	F	F	G	G	G	G	0	5	6	Fair to good
Rimmed	G	G	G	G	G	G	G	G	G	G	0	0	9	Good
Shaker rimmed	G	F	G	G	G	P	F	G	G	G	1	2	6	Fair to good
Capped	D	G	G	G	G	P	P	G	G	G	1	0	8	Good
Capped	E	G	F	P	G	G	G	P	F	G	3	1	5	Poor to good
Semikilled	X	P	F	G	G	G	G	F	F	F	0	5	4	Fair to good
Killed	Z	P	F	G	P	G	G	G	G	G	2	1	6	Poor to good
E6020 ELECTRODES														
Rimmed	D	G	G	G	G	G	G	G	G	G	0	0	9	Good
Rimmed	E	G	G	G	G	G	G	G	G	G	0	0	9	Good
Rimmed	F	G	G	G	G	G	G	G	G	G	0	0	9	Good
Rimmed	G	G	G	G	G	G	G	G	G	G	0	0	9	Good
Shaker rimmed	G	G	G	G	G	G	G	G	G	G	0	0	9	Good
Capped	D	G	G	G	G	G	G	G	G	G	0	0	9	Good
Capped	E	G	G	G	G	G	G	G	G	G	0	0	9	Good
Semikilled	X	G	G	G	G	G	G	G	G	G	0	0	9	Good
Killed	Z	G	G	G	G	G	G	G	G	G	0	0	9	Good

[1] G = Good F = Fair P = Poor

The usability ratings are based on a weighted combination of ratings of individual factors such as arc stability, metal transfer characteristics, pool action, spatter, ease of deposition, etc. Three commercial electrodes of the E6010, E6012, and E6020 type were used as standards of comparison, the usability rating for these electrodes was "Good".

TABLE B-5

Burn-Off Rates of Experimental Covered Electrodes Made with 3/16-Inch Core Wires from Various Heats

Steel Type	Heat	Ingot Location	Billet Location	Average Burn-Off Rate, In./Min.[1] E6010	E6012	E6020	Bare
Rimmed	D	1	t	8.4	10.7	9.4	11.2
			m	8.3	10.6	9.0	—
			b	8.2	10.4	8.9	10.8
Rimmed	E	2	t	8.6	10.6	—	10.6
			m	8.8	10.5	—	—
			b	8.7	10.6	—	12.5
Rimmed	F	2	t	8.8	10.3	8.4	11.5
			m	8.7	10.4	9.2	—
			b	8.8	10.2	9.6	10.5
Rimmed	G	2	t	8.5	10.4	9.8	8.9
			m	8.4	10.3	9.9	—
			b	8.4	10.9	9.4	10.0
Shaker rimmed	G	2a	t	8.2	10.4	—	12.1
			m	8.5	10.4	—	—
			b	8.8	10.5	—	11.7
Capped	D	1a	t	8.6	11.0	—	11.2
			m	8.6	10.5	—	—
			b	8.5	10.9	—	11.4
Capped	E	2a	t	8.2	9.6	9.8	12.4
			m	8.2	9.6	9.7	—
			b	8.5	9.7	9.3	11.1
Killed	Z	2	t	8.4	10.8	—	17.4
			m	8.5	11.4	—	—
			b	8.6	12.2	—	17.0

[1] Welding conditions:
E6010 — Direct current reverse polarity, 170 amp., 26 arc volts.
E6012 — Direct current straight polarity, 180 amp., 22 arc volts.
E6020 — Direct current straight polarity, 180 amp., 29 arc volts.
Bare — Direct current straight polarity, 180 amp., optimum arc volts.

TABLE B-3

Influence of Core Wire Ingot Location on Usability Rating of Experimental Covered Electrodes

Ingot Location in Heat	Dr t	m	b	Er t	m	b	Fr t	m	b	Gr t	m	b	Grr t	m	b	Dr t	m	b	Er t	m	b	Xr t	m	b	Zr t	m	b	Rating Count Poor	Fair	Good
E6010 Electrodes																														
1	G	G	G	G	F	G	G	F	G	F	G	G	G	G	G	G	G	F	G	G	G	G	G	G	G	G	G	0	4	28
2	G	G	G	G	G	G	G	G	G	G	G	F	F	F	F	G	G	F	G	G	G	G	G	G	G	G	G	0	5	27
3	G	G	G	G	G	G	G	G	G	F	F	G	F	F	F	G	G	F	G	G	G	G	G	G	G	G	G	0	7	26
E6012 Electrodes																														
1	P	P	P	G	G	G	F	G	G	G	G	G	F	G	G	G	G	F	P	F	F	G	P	F	G	P	F	5	6	16
2	P	F	G	G	G	F	F	F	G	G	G	G	F	F	G	G	P	F	G	G	G	P	G	G	G	G	G	5	5	17
3	P	P	G	P	F	F	G	G	G	G	G	G	G	G	G	G	G	G	P	G	G	F	F	F	G	G	G	4	5	18

TABLE B-4

Influence of Core Wire Billet Location on Usability Rating of Experimental Electrodes

Billet Location in Ingot	Dr 1	2	3	Er 1	2	3	Fr 1	2	3	Gr 1	2	3	Grr 1	2	3	Dr 1	2	3	Er 1	2	3	Xr 1	2	3	Zr 1	2	3	Rating Count Poor	Fair	Good
E6010 Electrodes																														
Top	G	G	G	G	G	G	F	G	F	G	F	F	G	F	F	G	G	G	G	G	G	G	G	G	G	G	G	0	5	22
Middle	G	G	G	F	G	G	G	G	G	G	F	F	G	G	G	G	G	F	G	G	G	G	G	G	G	G	G	0	5	22
Bottom	G	G	G	G	G	G	G	G	G	G	F	G	G	F	F	G	G	F	F	G	G	F	G	G	G	G	G	0	6	21
E6012 Electrodes																														
Top	P	P	P	G	G	P	G	F	G	G	G	G	F	P	G	G	G	G	G	G	P	F	G	F	P	P	G	8	4	15
Middle	P	F	P	G	G	F	G	G	G	G	F	G	G	F	G	G	F	G	G	G	P	F	G	F	G	G	G	8	8	16
Bottom	P	G	G	G	F	F	P	G	G	G	G	G	G	G	G	G	G	G	G	G	P	P	G	G	G	G	G	3	6	20

TABLE B-6

Influence of Billet Location in Ingot on Surface Pitting Produced by 5/16-Inch E6010 Electrodes in Vertical Down Fillet Welds[1]

Steel Type	Heat	Average Number of Pits Per Inch of Fillet Weld: Top Roller Ingot Location 1	2	3	Aver. age	Middle Roller Ingot Location 1	2	3	Aver. age	Bottom Roller Ingot Location 1	2	3	Aver. age
Rimmed	D	17	12	15	14	13	9	8	11	6	7	4	5
Rimmed	E	9	10	7	9	6	8	5	6	2	6	5	4
Rimmed	F	7	4	10	7	4	5	6	5	5	2	4	5
Rimmed	G	17	12	9	9	7	22	8	9	5	3	5	4
Shaker rimmed	G	12	13	7	11	8	12	5	8	6	3	1	3
Capped	D	10	7	10	9	11	8	7	9	6	6	5	7
Capped	E	9	11	5	8	9	5	4	7	10	3	2	5
Semikilled	X	5	5	6	4	5	4	3	4	4	1	4	4
Killed	Z	2	1	2	2	4	2	3	3	2	2	3	2

[1] Automatic welding used to make vertical down fillet welds on killed steel plate using straight polarity direct current, 180 amperes, 25-27 arc volts.

APPENDIX C

TABLE C-1

Tensile Strength of All Weld Metal Specimens Made with Experimental E6010 Electrodes in Killed Steel Base Plate[1,2]

Steel Type	Core Wire Heat and Ingot	Billet Location	Yield Strength, psi.[3]	Ultimate Tensile Strength, psi.	Elongation in 2 Inches, Per Cent	Reduction in Area, Per Cent
Rimmed	D1	t	57,800	68,200	24	45
		m	58,100	68,100	23	43
		b	57,400	68,800	25	42
Rimmed	F2	t	58,800	70,200	25	46
		m	59,300	69,100	24	37
		b	57,400	68,400	26	47
Capped	E2	t	61,900	72,300	23	36
		m	61,200	73,300	23	42
		b	55,600	67,900	26	54
Killed	Z2	t	59,500	70,200	27	43
		m	60,800	71,600	23	40
		b	59,000	69,800	22	38
Average			59,000	70,000	24	42

[1] All values in Tables C-1 to C-6, inclusive, are the average of tests of two 0.505-inch round bars.
[2] For killed steel plate data, see Table A-4, Appendix A.
[3] Drop-of-beam yield strength.

TABLE C-2

Tensile Strength of All Weld Metal Specimens Made with Experimental E6012 Electrodes in Killed Steel Base Plate

Core Wire			Yield Strength, psi.[1]	Ultimate Tensile Strength, psi.	Elongation in 2 Inches, Per Cent	Reduction in Area, Per Cent
Steel Type	Heat and Ingot	Billet Location				
Rimmed	D1	t	66,000	78,700	17	29
		b	64,900	76,500	20	39
Rimmed	F2	t	66,300	78,000	20	36
		b	65,500	77,800	18	35
Capped	E2	t	65,000	78,300	18	36
		b	64,300	77,000	19	37
Killed	Z2	t	64,800	75,500	16	28
		b	64,800	75,800	16	28
Average			65,200	77,200	18	34

[1] Drop-of-beam yield strength.

TABLE C-3

Tensile Strength of All Weld Metal Specimens Made with Experimental E6020 Electrodes in Killed Steel Base Plate

Core Wire			Yield Strength, psi.[1]	Ultimate Tensile Strength, psi.	Elongation in 2 Inches, Per Cent	Reduction in Area, Per Cent
Steel Type	Heat and Ingot	Billet Location				
Rimmed	D1	t	57,000	64,500	20	41
		b	54,500	62,800	24	50
Rimmed	F2	t	54,000	63,800	24	51
		b	53,300	64,500	25	47
Capped	E2	t	53,800	63,500	19	41
		b	55,300	63,800	24	56
Killed	Z2	t	57,800	66,500	20	38
		b	59,300	66,300	22	50
Average			55,600	64,500	22	47

[1] Drop-of-beam yield strength.

TABLE C-4

Tensile Strength of All Weld Metal Specimens Made with Experimental E6010 Electrodes in Rimmed Steel Base Plate[1]

Core Wire			Yield Strength, psi.[2]	Ultimate Tensile Strength, psi.	Elongation in 2 Inches, Per Cent	Reduction in Area, Per Cent
Steel Type	Heat and Ingot	Billet Location				
Rimmed	D1	t	56,000	68,300	20	33
		m	54,000	65,400	22	35
		b	51,500	64,100	27	47
Rimmed	F2	t	51,500	64,500	26	54
		m	52,300	64,500	20	36
		b	51,000	64,400	23	41
Capped	E2	t	55,200	66,600	20	33
		m	56,800	69,400	21	35
		b	54,800	66,900	20	35
Killed	Z2	t	55,500	67,500	19	43
		m	56,000	69,200	21	37
		b	56,000	69,100	18	34
Average			54,200	66,700	21	38

[1] For rimmed-steel plate data, see Table A-4, Appendix A.
[2] Drop-of-beam yield strength.

TABLE C-5

Tensile Strength of All Weld Metal Specimens Made with Experimental E6012 Electrodes in Rimmed Steel Base Plate

Core Wire			Yield Strength, psi.[1]	Ultimate Tensile Strength, psi.	Elongation in 2 Inches, Per Cent	Reduction in Area, Per Cent
Steel Type	Heat and Ingot	Billet Location				
Rimmed	D1	t	65,800	75,600	15	24
		m	65,300	77,300	16	26
		b	64,300	77,100	20	32
Rimmed	F2	t	65,000	77,000	15	28
		m	67,300	79,400	18	31
		b	65,300	78,300	19	37
Capped	E2	t	66,000	80,400	18	30
		m	66,000	78,900	17	32
		b	64,300	77,300	16	31
Killed	Z2	t	66,800	79,100	18	32
		m	66,500	77,900	14	27
		b	65,000	77,700	16	30
Average			65,600	78,000	17	30

[1] Drop-of-beam yield strength.

TABLE C-6

Tensile Strength of All Weld Metal Specimens Made with Experimental E6020 Electrodes in Rimmed Steel Base Plate

Core Wire			Yield Strength, psi.[1]	Ultimate Tensile Strength, psi.	Elongation in 2 Inches, Per Cent	Reduction in Area, Per Cent
Steel Type	Heat and Ingot	Billet Location				
Rimmed	D1	t	59,800	66,700	26	47
		m	58,500	66,100	22	47
		b	56,800	64,500	20	47
Rimmed	F2	t	58,800	67,100	22	52
		m	59,300	66,300	23	52
		b	54,000	64,200	24	45
Capped	E2	t	57,000	66,200	22	46
		m	54,800	66,700	22	51
		b	57,000	65,000	20	50
Killed	Z2	t	58,000	68,000	22	49
		m	58,300	66,400	26	57
		b	56,700	65,400	24	58
Average			57,400	66,100	23	50

[1] Drop-of-beam yield strength.

TABLE C-7

Composition of Weld Metals Deposited by Various Experimental E6010 Electrodes

Heat	Steel Type	Ingot Location	Billet Location	Chemical Composition, Per Cent[1]				
				C	Mn	P	S	Si
D	Rimmed	1	t	0.11	0.38	0.013	0.032	0.19
			m	0.12	0.37	0.013	0.032	0.19
			b	0.08	0.38	0.010	0.023	0.19
E	Rimmed	2	m	0.06	0.33	0.010	0.025	0.16
F	Rimmed	2	m	0.08	0.34	0.014	0.026	0.15
G	Rimmed	2	m	0.07	0.37	0.014	0.027	0.17
G	Shaker rimmed	2	m	0.06	0.32	0.014	0.032	0.16
D	Capped	2	m	0.07	0.29	0.013	0.036	0.17
E	Capped	2	m	0.10	0.37	0.010	0.025	0.17
X	Semikilled	2	m	0.08	0.37	0.011	0.022	0.19
Z	Killed	2	t	0.08	0.36	0.012	0.021	0.17
			m	0.07	0.38	0.011	0.021	0.17
			b	0.06	0.32	0.011	0.021	0.17

[1] Results of wet chemical analysis. By spectrographic analysis:
Cu — 0.06 per cent Max.
Cr — 0.03 per cent Max.
Ni — 0.04 per cent Max.

Stresses in "Head-to-Shell" Juncture of Pressure Vessels

A résumé of literature theories in the design of pressure vessel head, application of these theories, tests of stress distribution under pressure and correlation of test results with theory

by R. G. Sturm, H. L. O'Brien, E. Wetterstrom and J. Evans

BEGUN in July 1947, the Purdue Project of the Design Division of the Pressure Vessel Research Committee[1] was directed toward the end result of presenting data for new rules for pressure vessel design. The Design Division recommended as a first step the investigation of static stresses in the head-to-shell juncture of a vessel subjected to internal pressure. The first effort in approaching this problem consisted of a survey of literature. On the basis of this survey, it was concluded that the Love-Meissner Approximation was a valid theoretical analysis, accurate enough for comparison purposes pending the completion of a more thorough analysis.[2] With the problem and analytical solution decided upon, the next task was to obtain actual experimental results and to draw conclusions by correlation of the theory and results.

The scope of the immediate investigation was limited to the particular problem of a conical head joined to a cylindrical shell. The vessels were limited to models 8 in. in diameter with 90° cone heads. The general procedure employed in attacking this problem may be summarized as follows: (1) conduction of the aforementioned survey of literature for existing theories, (2) application of these theories to the particular vessels under consideration, (3) hydrostatic tests carried out on these vessels to determine the stress distributions, (4) analysis of test results and the correlation of these results with theory, and (5) summary of the salient results of such a correlation and analysis.

RÉSUMÉ OF LITERATURE

A general résumé of the literature relative to pressure vessels has been made and is on file in the office of the Pressure Vessel Research Committee. The theoretical analyses selected from a great number of technical papers and considered for this investigation have been those involving solutions to the stress distribution problem in the head-to-shell juncture of a cone embodying a 90° included angle and a cylindrical shell. These analyses, in turn, may be divided into two groups, those with cone and shell thicknesses equal, and those for which the cone thickness is greater by the secant of one-half the apex angle. The several approximate methods[3] reviewed were essentially identical to the Love-Meissner approximation proposed by W. R. Burrows of the P.V.R.C. Design Division.[4]

The Love-Meissner solution as applied to the test pressure vessels with cylindrical shells and conical heads consisted of a summation of forces and moments acting upon an element of cylinder to obtain the solution for the cylindrical section. The solution for the conical section, in turn, was found by using the theoretical solution for an equivalent cylinder. Then, assuming the radius of curvature perpendicular to the element of the cone to be the distance to the axis of the cone, a reasonable engineering approximation in the neighborhood of the juncture of the shell and head was obtained.

APPLICATION OF APPROXIMATE THEORY

No special analysis has been made to account for the presence or absence of a knuckle region at the juncture of head to shell. The solution for the conical section has been found to indicate the trends even for those cases in which the head consisted of a cone with a knuckle radius. This approximation serves well as a comparison for test data.

The results obtained by the application of the theoretical analysis to 8-in. diameter models 1, 2, 3 and 5 are shown as the solid lines in Figs. 1–4. These curves have been plotted together in order that comparisons showing the effects of the geometry of the junctions may be readily made. Another comparison, involving D/t

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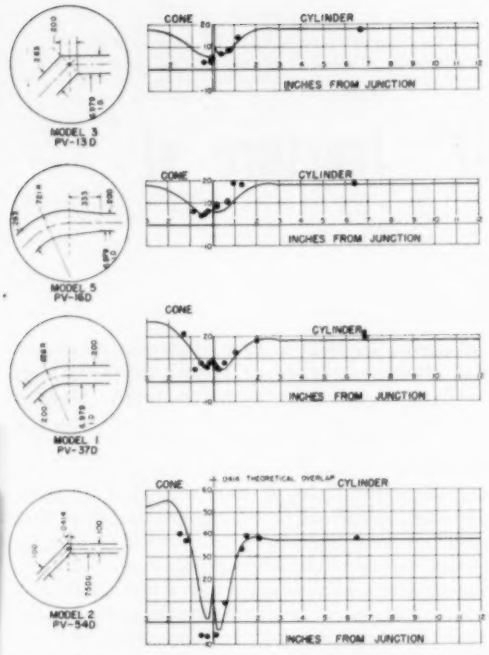

Fig. 1 Measured and computed inner circumferential stresses—models 1, 2, 3 and 5

Stress based on an internal pressure, P, of 1 psi.

ratios, may be had by examination of the curves for models 1 and 2, the two experimental test vessels having the cone thickness equal to the shell thickness. These curves are also given in Figs. 1–4.

The stress distribution for Model 3 was obtained directly from the theoretical analysis discussed above. Models 5, 2 and 1, however, had to be analyzed in a slightly different fashion.

Model 5, as can be seen in Figs. 1–4, inclusive, has tapers inside and out which join the knuckle to the straight cylindrical shell and gradually reduce the thickness to that of the shell. The calculated stress curves for this vessel were based upon the distributions of shear and moment obtained for a vessel without a knuckle and having a cone thickness equal to that of the shell multiplied by the secant of one-half the apex angle. The bending moment thus obtained was inserted in the usual equation, $S = MC/I$, to obtain the distribution of the bending stress for the tapered section. Tensile stresses were obtained by a consideration of the varying areas. This procedure developed the theoretical distributions which gave practical continuities of stress at the junction of the head to the cylinder.

The theory used for the numerical calculations for models 1 and 2 utilized exact values for the cone thicknesses rather than assuming a cone thickness equal to that of the shell multiplied by the secant of one-half the apex angle. The calculations were carried through using the actual thicknesses of the vessels.

DESCRIPTION OF MODELS

The details of the knuckle region of each of the four models tested are shown in Figs. 1–4.

Model 2 is a $^1/_6$-scale model of a large vessel now being studied at Purdue. The other three models have variations in wall thickness and geometry of junction as indicated.

In order that the properties of the material used in forging the test vessels be known, specimens were machined from sections of the same pipe from which the test vessels were forged. Of the four preliminary specimens made, two were tested by the Standard Oil Co. (Indiana) and two were tested at Purdue. The chemical analysis and physical test results follow.

Chemical analysis

C	*Mn*	*P*	*S*	*Si*
0.18	0.43	0.010	0.024	0.02

Physical test

	PU-A1	*PU-A2*	*PU-A4*	*PU-A5*
Yield point, psi.	30,750	30,000	30,000	32,800
Ultimate strength, psi.	58,500	57,500	51,500	51,500
Reduction of area, %	63.1	63.1	40.6	41.4
Elongation in 2 in., %	37	39	47.5	45.3
Brinell hardness	132	132	132	119

These physical tests are by no means considered complete. Representative samples were taken throughout the length of the pipe from which the vessels were forged for a complete set of tests including tension, compression and torsion. In addition, sufficient auxiliary measurements to permit the construction of true stress-true strain curves will be made. One set of specimens is being tested at Purdue and one set is being tested by the materials division of P.V.R.C.

At the outset it seemed desirable, for reasons of project economy, to utilize water as the pressure medium. This raised the problem of waterproofing the SR-4 electric strain gages for conditions of hydrostatic pressure. Many materials were recommended and tried, but none proved satisfactory for pressures exceeding 300 psi. The compounds proving efficient for insulation against water at no pressure were "Miracle" adhesive and a combination of Petrosene-A wax covered with "Ozite." The complete failure under high pressure of all the waterproofing materials tried precluded the use of water as a means of applying internal pressure. Subsequently, dielectric fluids were used.

The techniques of testing the four model vessels were much the same for all tests. The model was, first of all, cleaned and sprayed with "Stresscoat" and subjected to an internal pressure ranging to about four-fifths of the allowable A.S.M.E. working pressure for that vessel. The resulting stresses were generally so small that it was necessary to chill the coating with a blast of CO_2 to bring out the crack pattern clearly. A typical Stresscoat pattern is shown in Fig. 5. These patterns

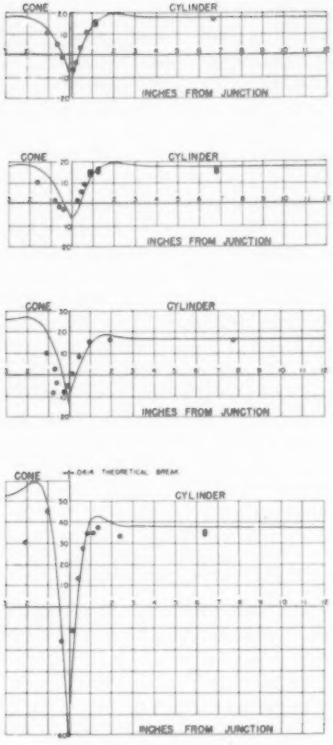

Fig. 2 Measured and computed outer circumferential stresses—models 1, 2, 3 and 5

Stress based on an internal pressure, P, of 1 psi.

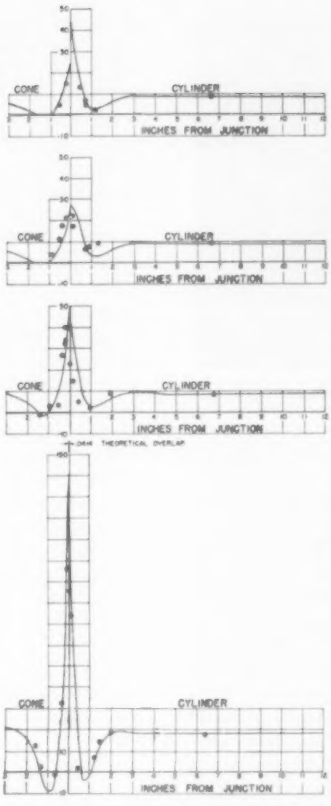

Fig. 3 Measured and computed inner longitudinal stresses—models 1, 2, 3 and 5

Stress based on an internal pressure, P, of 1 psi.

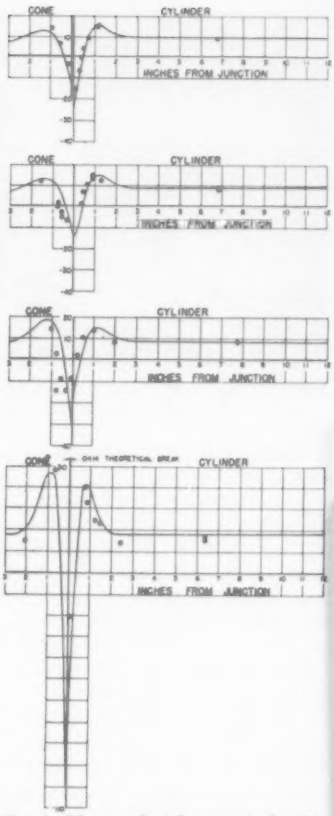

Fig. 4 Measured and computed outer longitudinal stresses—models 1, 2, 3 and 5

Stress based on an internal pressure, P, of 1 psi.

aided in locating strain gages and afforded a confirmation of the location of critical points indicated by the theory. After the Stresscoat test, the vessel was cleaned and SR-4 gages of appropriate length were applied at the positions determined as significant. The points of significance were selected with due consideration of the theoretical stress curves and the Stresscoat patterns.

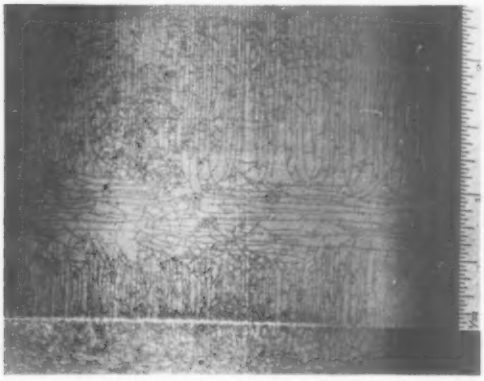

Fig. 5 Stresscoat patterns, model 3—shell, coat 1202, 800 psi., 4 min.—CO_2 blasted and etched

The gages were applied in accordance with established techniques utilizing Duco household cement as the adhesive. Figure 6 shows the laboratory equipment for testing and applying gages. At all points of strain measurement, two SR-4 gages were used. One was oriented to indicate longitudinal strains and one was oriented to indicate circumferential strains.

Once the strain gages were located and applied, both inside and out, the vessel was closed for test purposes. The pressures were applied gradually in the desired increments and held constant during the period required for recording data. Pressure increments were added until yielding was impending. The pressure was then released and applied again in increments until general yielding occurred.

It was possible to make individual readings of strain on each gage by means of the selective switching box

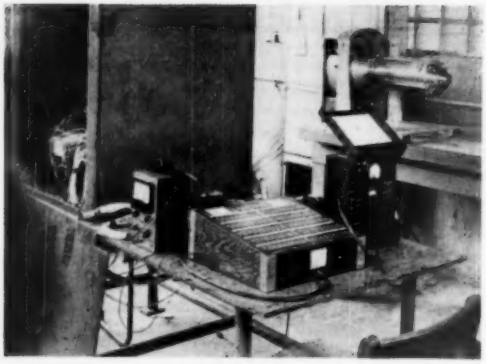

Fig. 6 Model 3 being tested. Model 5 being prepared for tests in center background

shown in Fig. 6. This unit made it possible to read any gage at any location.

The order in which the vessels were tested follows: model 3, model 5, model 2, and model 1.

The procedure followed in testing Model 3 varied from the general procedure followed for the others. The principal reason for this deviation was the fact that the initial technique used in testing this vessel proved unsatisfactory. It was first thought that a combination of beeswax and castor oil would effectively insulate the SR-4 gages from the water pressure medium. Upon application of hydrostatic pressure, however, short circuits developed and rendered all readings invalid. The next attempt was made utilizing Petrosene-A wax and "Miracle" adhesive to insulate the gages. Since transformer wire had been used in the first test, it was further decided to change to a plastic covered waterproof single conductor wire. By developing a new switching unit made up of 100 microswitches, it was possible to expedite the reading of gages during tests. Water was again employed as a pressure medium and, as before, developed short circuits in the wiring system at hydrostatic pressures exceeding 300 psi. The practical difficulties of insulating SR-4 strain gages against water pressure were so overwhelming that it was decided to test the models by applying pressure with nitrogen. The internal gages of Model 3 were replaced, the vessel closed and pressure applied from a nitrogen cylinder. Although the gages were unprotected, readings were successfully taken through 1200 psi., at which time local yielding was apparent and it was considered unsafe to continue with the nitrogen pressure. The pressure medium was changed to transformer oil. Transformer oil was selected because of its dielectric properties in the hopes that strain readings could be taken during plastic yielding. The gage readings were successful and a complete set of data for plastic yielding was obtained. The pressure was raised until the vessel broke at 2750 psi.

The procedure employed in testing Model 5 was essentially that of the general procedure. Once the gages were located and applied, nitrogen was introduced to the vessel and two loadings made in order that the gages would be sufficiently "exercised." Following this, a series of pressures were applied so that readings could be taken within the elastic range. When local yielding occurred, the system was again changed to one employing transformer oil and readings were obtained during plastic yielding. This vessel was not tested to destruction.

Aside from minor changes in technique, the tests on models 1 and 2 followed a pattern similar to that of model 5, neither vessel being tested to destruction.

For models 3, 5 and 2 Stresscoat was applied to the outer surface of the vessels and the vessels subjected to internal pressure from the nitrogen cylinder.

For the one vessel tested to destruction, model 3, a metallurgical examination was made at a number of sections at the knuckle and at points removed from the fracture. These examinations, generally, showed that when strains amounted to more than 10% the crystallographic structures indicated elongation of the grains in the direction of the principal extensions. For strains as small as 3% and under, there seems to be an indication of granular elongation in the principal direction of extension, but only an indication.

ANALYSIS OF MEASURED STRAINS

The measured stresses were obtained from the strain readings of the SR-4 strain gages. The customary equations,

$$S_L = \frac{E}{(1 - \gamma^2)}\left[\epsilon_L + \gamma\epsilon_C\right]$$

and

$$S_C = \frac{E}{(1 - \gamma^2)}\left[\epsilon_C + \gamma\epsilon_L\right]$$

were used, in which

S_L = longitudinal stress, psi.
S_C = circumferential stress, psi.
E = modulus of elasticity, psi.
γ = Poisson's ratio
ϵ_L = longitudinal strain, in. per inch
ϵ_C = circumferential strain, in. per inch

The values of stress, S_L and S_C, for a 1-lb. internal pressure, computed from the average strain for an interval of 1 psi., are determined by the slope of the pressure-strain curves within the elastic range. The results obtained in this manner are shown as plotted points on the curves in Figs. 1 through 4. Typical pressure-strain curves for model 1 are shown in Figs. 7 and 8.

In order to illustrate the significance of plastic yielding in the knuckle region, the strains for the longitudinal gages shown in Figs. 7 and 8 have been replotted to suitable scales in Figs. 9 and 10, respectively. Attention is directed to the fact that the gages from which this data were obtained were located at the center of the knuckle region. The data in Fig. 9 refers to the center of the knuckle on the inside and the data in Fig.

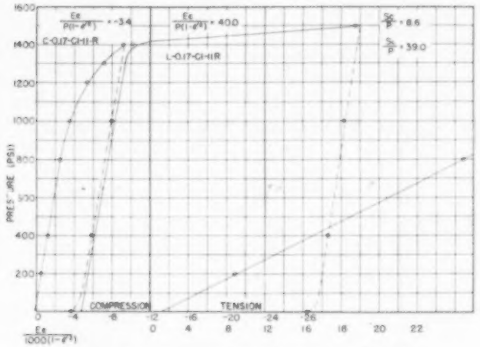

Fig. 7 Internally measured strains, Model 1

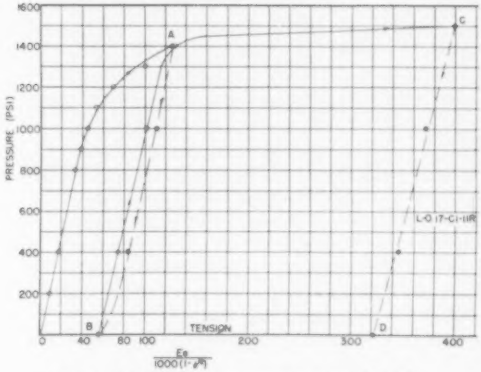

Fig. 9 Internally measured strains, Model 1

10 refers to the center of this knuckle on the outside. Figures 11 and 12 show stress-strain curves corresponding to the properties of the material in the vessel with the arrowed lines representing the stress-strain cycles of Figs. 9 and 10, respectively. The yield strength of the material in tension was determined as 26,900 psi. from the pressure at general yielding of the side walls of this vessel. It may be assumed that the yield strength in compression is the same value. With these values and the assumption that yielding occurs when the maximum possible shear stress is reached, the stress at the inside of the knuckle at which continuous yielding will occur is $Y_s - P$, where Y_s is the yield strength of the material and P is the internal pressure.

For example, as the pressure was gradually increased to 1400 psi., the gage line L-0.17-CI-11R showed a continuously increasing strain reaching the value of $E\epsilon/[1000\ (1-\gamma^2)] = 124$. This corresponds to a strain, $\epsilon = 0.0040$ in. per inch. Following the stress-strain curve to this value of strain (point A in Fig. 11) one finds that the strain is well beyond the elastic range and into the plastic flow range of strain.

When the pressure was removed, the strain at this gage recovered to a value of $E\epsilon/[1000\ (1-\gamma^2)] = 58$. This corresponds to a strain of 0.0017 in. per inch. It has been found that the strain recovery of metals occurs along a line parallel to the initial straight line position of the stress-strain diagram. Following such a line toward point B, one finds that the yield strength in compression is reached before the strain recovers to a value of 0.0017 in. per inch. The curve is then followed around the "knee" to the point B. This indicates that after the pressure is released, the locked-up stress on the inside of the knuckle is compressive and about equal to the yield strength.

When the pressure was reapplied, the stress rapidly increased to the yield strength in tension, passing through point A a second time and remaining at this value while the strain continued to increase with increasing pressure. When an internal pressure of 1500 psi. was reached, the strain had increased to $E\epsilon/[1000\ (1-\gamma^2)] = 400$, corresponding to $\epsilon = 0.0125$ in. per inch (point C in Fig. 11). Upon release of pressure, the strain decreased to $E\epsilon/[1000\ (1-\gamma^2)] = 312$, corresponding to $\epsilon = 0.0099$ in. per inch, point D. Again, following a line parallel to the initial straight line part of the stress-strain curve, one finds that the stress has reached a value in compression equal to the yield strength. Thus, the stress at the inside of the knuckle changed from a stress equal to the yield strength in tension, under test pressure, to a stress equal to the yield strength in compression when the load was released.

By following the same procedure as above, Fig. 12

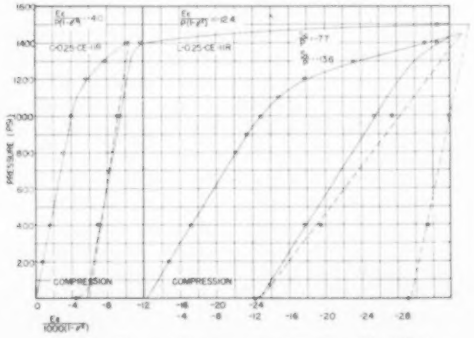

Fig. 8 Externally measured strains, Model 1

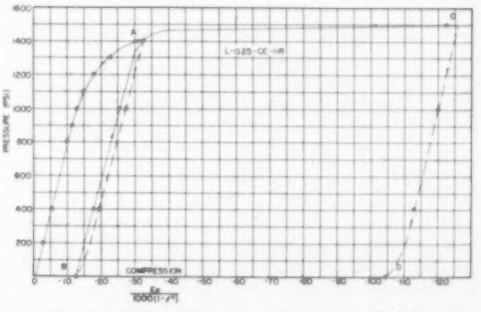

Fig. 10 Externally measured strains, Model 1

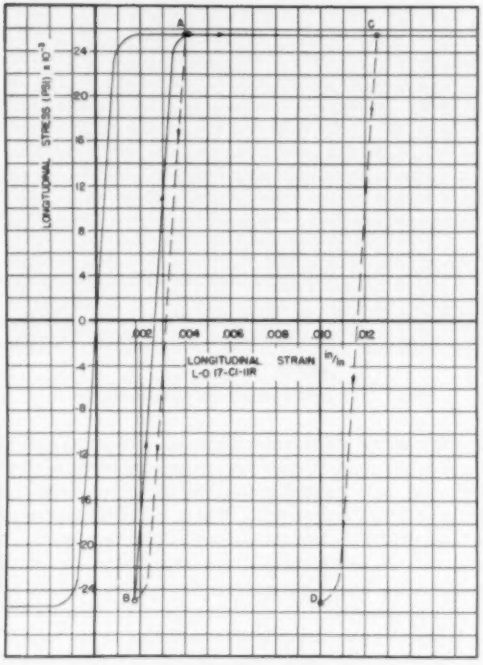

Fig. 11 Internal stress-strain curves, Model 1

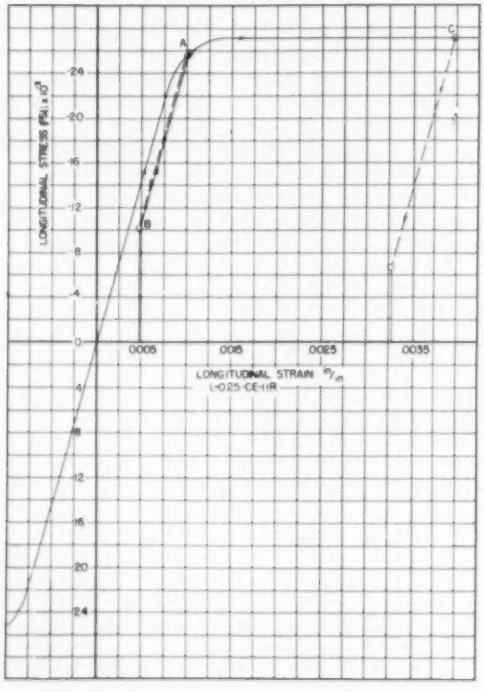

Fig. 12 External stress-strain curves, Model 1

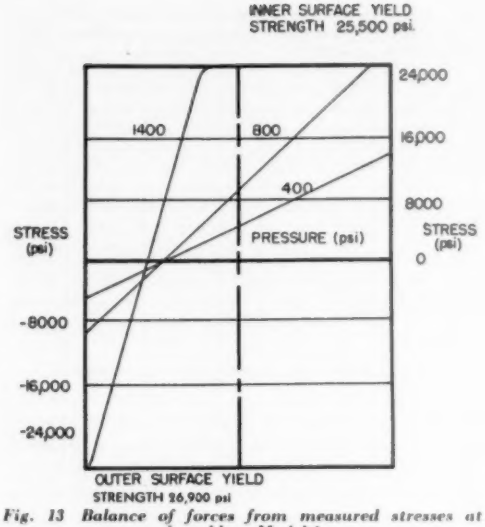

Fig. 13 Balance of forces from measured stresses at knuckles—Model 1

was obtained and a corresponding analysis showed the longitudinal stress at the outside of the knuckle to be much less severe, the stress range remaining compressive at all times.

To check the consistency of these deductions, the longitudinal stresses on the inside and outside of the knuckle have been plotted as shown in Fig. 13. At 400 psi. internal pressure, all stresses are elastic and the distribution nearly linear. The net area under the curve of stress distribution defines a force and is in agreement with the total force per inch of circumference necessary to hold the head onto the shell. Similarly, for 800 psi. and 1400 psi., the net areas again indicate consistent forces at the center of the knuckle. The fact that this balance holds for stresses in the plastic range (1400 psi. pressure) substantiates the validity of this analysis.

CORRELATIONS

A. Materials

The effect of heat treating the material in the vessels may be noted in the tensile strengths and elongations. Tests PU A-1 and PU A-2 at the Standard Oil Co. (Indiana) were made before heat treatment, whereas specimens PU A-4 and PU A-5 were tested after heat treatment. The relative decrease in reduction of area and increase in elongation indicate that the material behaved more uniformly after heat treatment than before. This fact justifies the extreme care taken in heat treating the material prior to test.

B. Theory vs. Test Results in the Elastic Range

A critical examination of Figs. 1 through 4, representing the data for the models, shows that while there

are a few local discrepancies, the general trends of the stress distribution for the head-to-cylinder junction are remarkably the same whether computed by the Love-Meissner approximation or determined by actual measurement.

In those cases for which a torus section was used, the plane of intersection was chosen as the point of tangency between the torus and the shell. Theoretically, one would expect the maximum stresses to occur near the center of the torus section, not at the point of tangency. The test results indicate that the maximum stress does occur a short distance on the torus side of the plane of intersection indicated above. On the basis of the theoretical analysis alone, one can observe for model 2, which has a wall thickness one-half as great as the other vessels, that the compressive stresses in the circumferential direction are much more prominent than for the vessels with thicker walls. This suggests that if the wall thickness were still further reduced or, generally speaking, the ratio of diameter to thickness increased, the circumferential compressive stresses would become the significant stresses and thereby govern design. The experimental results verify this trend.

A close examination of the comparison between measured and computed stresses for these thin-walled vessels indicates that the Love-Meissner approximation is in very close agreement with the actual behavior of the shells. Using the computed values for the maximum longitudinal stress on the inside at the juncture, it follows that the pressure necessary to cause localized yielding for model 3 is 580 psi., which is only 78% of the allowable working pressure (745 psi.) computed on the basis of average stress in the side wall equal to one-fourth of the ultimate strength.

For model 5 the pressure causing localized yielding is 1030 psi., which is 138% of the allowable working pressure.

For model 1 the pressure causing localized yielding is again 580 psi., or 78% of the allowable working pressure.

For model 2 the pressure causing localized yielding over an extremely narrow band is 193 psi. which is only 52% of the allowable working pressure (372 psi.). Attention is directed to the fact that the maximum circumferential compressive stress at the juncture of model 2 is indicated as 22,300 psi. at the allowable working pressure.

C. Test Results in the Plastic Range

Reference to Fig. 9, which shows the measured longitudinal strains on the inside center of the torus section for model 1, shows that yielding at the gage location was apparent for all pressures above the allowable working pressure. In Fig. 11 the strains corresponding to test pressures of twice the working pressures reveal that when the pressure was removed, the residual stress at the gage was a compression equal to the combined yield strength for the material.

Figures 10 and 12 indicate that the longitudinal compressive strains on the outside of the vessel did not return to zero when the pressure was removed. This means that after the vessel had been tested and pressure removed, the state of locked-up stresses at the juncture was one of compressive stresses on the surfaces at the center of the torus. Consequently, a locked-up tensile stress at the center of the wall must exist. At points near the center (not more than the thickness of the wall from the center) the stress situation is entirely different. Therefore, for a very ductile material, one would expect to find fatigue failures occurring at points near to but not at the location of maximum static stress. For very brittle materials, or materials at temperatures below critical, the highly localized strains at the center of the torus might be expected to cause fracture. The situation is further aggravated by sharp corners such as those occurring in models 2 and 3, but is not nearly so severe for vessels with thicker heads and gradual tapers, such as occur in Model 5. However, Model 5 with the thicker head and tapers would be expected to have lower stresses.

One important observation was made in conjunction with all models: that when yielding in the sidewalls first started, there was no measurable departure from the original geometry of the knuckle region.

CONCLUSIONS

From the experience thus far obtained with the model vessels and the data obtained during the course of this investigation, the following conclusions relative to the general action of pressure vessels have been drawn.

1. For conical heads attached to cylindrical vessels, the Love-Meissner approximation gives a satisfactory indication of the stress distribution in the vicinity of the juncture within the elastic range.

2. This approximation gives an indication of the elastic stress distribution for toriconical heads having a short knuckle radius.

The Love-Meissner approximation has thus far not been applied to heads having relatively large knuckle radii.

3. At pressures equal to the A.S.M.E. allowable working pressure, stresses beyond the yield strength may be expected in the longitudinal direction at the juncture except where the cone and knuckle thicknesses are appreciably greater than that of the side walls.

4. When pressures equal to one and one-half to twice the A.S.M.E. allowable working pressure are applied to vessels with conical or toriconical heads, plastic yielding occurs.

5. When the test pressure is released, locked-up stresses in longitudinal compression are developed on the inside at the juncture where high tensile stresses existed under pressure.

6. The occurrence of such highly localized yielding did not produce a measurable departure from the original geometry of the over-all vessel.

7. The significance of fabrication tolerances upon

the distribution of stresses cannot be evaluated from these models. Therefore, subsequent tests of vessels fabricated in accordance with standard procedure are needed.

References

[1] As stated in its by-laws:
Article 1(c) "The Pressure Vessel Research Committee was organized by the Welding Research Council as the result of resolutions adopted by executives, engineers, fabricators, users and scientists at a conference called for this purpose on March 15, 1945."
Article 2(a) "To encourage, promote and conduct needed research in the Pressure Vessel field, including consideration of materials, design, fabrication and testing."

[2] Watts, Burrows, "The Basic Elastic Theory of Vessel Heads Under Internal Pressure," presented to A.S.M.E., December 1947.

[3] Moir, C. M., "Direct and Bending Stresses in Cylindrical and Thin Walls," *Glasgow Royal Technical College Journal*, Vol. 3, p. 137 (1933–1936).
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Shrinkage Distortion in Welding

by W. Spraragen and W. G. Ettinger

THIS report is an attempt to systematize information available in the literature on the subject of Shrinkage Distortion in the form of charts and formulas with suitable correction factors. In view of the fact that more than 20 variables are involved, arbitrary assumptions have been made throughout which the authors believe represent average conditions. Every firm is urged to simplify and modify this information into more accurate constants to suit conditions prevailing in its own shops.

EXPANSION, CONTRACTION, UPSETTING

When an edge of a plate is heated, such as in welding, it tends to expand in all directions. It is restrained in certain directions by the cold portions of the rest of the plate and therefore the total volumetric increase is taken care of by greater changes in the direction where the restraint does not exert its influence and upsetting action takes place. On cooling, the heated edge is restrained from shrinking by the colder portions of the plate. The yield point of the very hot metal is only a small fraction of that of the cold metal. This more rapid heating and cooling of the edges causes them to be shorter than they would have been with uniform heating and cooling of the entire section. We will ignore metallurgical volumetric changes.

This very simple explanation brings out that the following variables are involved:

1. Rate of temperature increase in each part and total temperature increase in each part.
2. Rate of temperature decrease in each part and total temperature drop in each part.
3. Volumes of metal undergoing expansion at each rate of temperature increase.
4. Volumes of metal undergoing contraction at each rate of temperature decrease.
5. Degree of constraint.

Inasmuch as information of this type cannot be readily dealt with by the welding engineer, an attempt will be made to simplify this information for average conditions in terms and measurements to which the welding engineer has access.

TRANSVERSE SHRINKAGE

Butt Welds

It is assumed that parts to be welded are tacked together, or if they are free to move that suitable allowance has been made for closure of the gap to a standard width. The amount of weld metal deposited depends upon the type of joint, the distance by which the plates are separated, the thickness of the plates and the reinforcement. The amount of heat input is proportional to the volume of the weld metal added. Conduction losses in thicker plates are, however, proportionately greater.

We have examined the data available, of which practically no two items are directly comparable, and have evolved the following simple formula for plates welded with covered electrodes:

Transverse Shrinkage (S) = Shrinkage of the heated plate section (S_p) + Shrinkage of Weld (S_w).

$$S = 0.2\,\frac{A_w}{t} + 0.05d$$

where

A_w = cross-sectional area of weld
t = thickness of plates (in.)
d = free distance (in.) (root opening)

The above formula is particularly applicable to plates thicker than one inch. If we have plates thinner than 1 in., it is probably better to use a value of 0.18 instead of 0.20 as the plate does not absorb so much heat. The formula attempts to take into account reinforcement

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and no reinforcement, number of layers and normal speeds. For sheets thinner than 1/4 in. the data are so much dependent on local conditions that no safe general rules will apply. For thinner plates "buckling" may be more serious than shrinkage.

Plate Width

The above formula applies for widths of plates (perpendicular to joint) greater than 3 in. For lesser widths it would be best to allow 20% less shrinkage than that shown because of less restraining influence in heating and cooling.

Length of Joint

For very short welds, less than 10 times the thickness, the above formula may not hold. It is based on longer welds properly tacked. The shrinkage in short welds will probably be 10 or 15% less than that indicated. On the other hand, for welds longer than 10 times the thickness, assuming adequate tacking, the average shrinkage becomes stabilized.

Degree of Applied Restraint

In general, the greater the degree of restraint the less the shrinkage and distortion and the greater the residual stresses. Clamping and tacking, therefore, tend to reduce the shrinkage. The greater the number of layers, within limits for manual welding, the greater is the restraint of the finished part and the less the shrinkage. This is offset to some degree by requiring greater heat input. The formula above is for average conditions. If it is necessary to reduce the amount of shrinkage below these average values for a given cross section of weld, the stringer bead type of deposit with cooling between passes should be used. This usually increases costs considerably. In thin plates and under very heavily restrained conditions it is desirable to use a welding sequence (step back, welding from center outward, etc.) which will reduce distortion and buckling still further. In some instances such procedures are necessary to avoid cracking of welds or the weldment itself.

Joint Design

Naturally, the type of joint influences the amount of shrinkage. The smaller cross-sectional area given by the double V- or U-joint as compared to a single V decreases the shrinkage. The formula is usually adequate to take care of the various types of joints commonly used. The formula is based largely on information obtained in "flat" welding.

Positions of Welding

For horizontal welding the shrinkage is generally less (about 20%) than that indicated by the formula.

Peening

For many years the welding industry has employed peening to control distortion. Hot peening is also used to prevent cracking of weld metal in regions of severe restraint. Depending upon the amount of peening, the shrinkage can be controlled from practically zero shrinkage to an amount 20% less than that obtained without peening. The latter figure is the one most commonly employed. In controlling transverse shrinkage cold peening is more effective than hot peening.

Thermal Factors

Preheating provides more uniform heating and cooling and therefore tends to minimize shrinkage. Depending upon the amount of preheat, reductions in shrinkage may be obtained—a 20% value is probably a safe one to use.

Welding Method

As indicated, the formula was derived for covered electrode arc welding. Bare wire welds have shrinkage values about 12% less than that shown by the above formula, and corresponding corrections should be made. Gas welding may be 20 to 50% higher or lower, depending on the width of the plates, that is, the relative areas of heated and cooled sections. If narrow plates are being welded, this process would have the same effect as preheating and would give less shrinkage than the arc welds. In submerged arc a very rapid rate of welding is attained. In abutting plates 1 to 2 in. in thickness with one or two pass submerged arc welding the shrinkage may be less than one-half of that given in the formula.

Cooling between passes increases the restraint and reduces the total shrinkage. Slow cooling tends to be more uniform cooling and therefore tends to decrease the over-all shrinkage somewhat. Postheating reduces residual stresses and promotes plastic flow but shrinkage may not be affected except very locally.

Fillet Welds

There is not a great deal of information available on the transverse shrinkage of fillet welds. Owing to the restraint usually encountered in making such welds, the shrinkage is not as serious as in butt welds. The following formulas may be helpful:

For Tee-joints with two continuous fillets:

$$\text{Shrinkage} = \frac{\text{leg of fillet}}{\text{thickness of plate}} \times 0.04 \text{ in.}$$

For intermittent welds—use correcting factor of proportional length of fillet to total length.

For fillets in lap joint (two fillet welds):

$$\text{Shrinkage} = \frac{\text{leg of fillet}}{\text{thickness of plate}} \times 0.06 \text{ in.}$$

For plates $^3/_8$ in. and under, "buckling" may be more serious than shrinkage.

For "deep fillet" technique the amount of shrinkage would be larger than that calculated from the visible fillet.

ANGULAR DISTORTION

Angular distortion is a result of an unsymmetrical shrinkage with respect to the width or across the thickness. The greater the number of layers for a V- or U-joint, the greater is the distortion. Interpass cooling tends to increase angular distortion. It may be controlled and reduced to zero by rigid clamping, by welding alternate layers of a double U- or V-joint, or by peening each layer in any type joint. Uncontrolled, a single V-joint in $^1/_2$ in. plate could assume a 10° distortion.

LONGITUDINAL SHRINKAGE

The longitudinal shrinkage is proportional to the length of the weld and is a function of the cross section of the weld and the cross sectional area of the colder portions of the plates resisting the expansion and contraction forces of the hot metal as the weld is made and cooled. Since the stress is not equally applied, not all of the area of the colder portion is equally effective in resisting the shrinkage and upsetting action. In built-up sections, such as structural members, ships, tanks, etc., it is difficult to calculate how much is effective. Therefore, it seems desirable that each industry compile over-all data for shrinkage in its own field. Information of this type is given in the three literature reviews referred to at the end of this article.

For cases where the area of the restraining plates is not more than 20 times the cross-sectional area of the total weld, one may use the following formula:

$$\text{Shrinkage (in. per inch)} = A_w A_p \times 0.025$$

A_w = area of weld (sq. in.)
A_p = area of restraining plates (sq. in.)

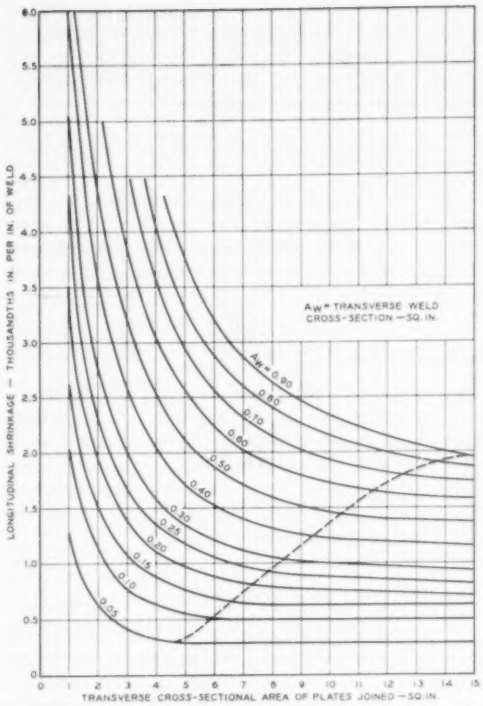

Fig. 1 Each curve represents the variation of unit longitudinal shrinkage as a function of the transverse cross-sectional area of the welded assembly for a given weld cross section

The shrinkage tends to become stabilized when the sectional area of the assembly exceeds a certain value, which is indicated by the dotted line. This chart has been adapted from Guyot[4]

If, however, the area of the restraining plates is more than 20 times the area of the weld, it is necessary to use the chart shown in Fig. 1.

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Weld Metal Properties at Low Temperatures

Tests of deposited metal of ferritic nickel steel electrodes containing up to 5% nickel, 25–20 stainless steel, Monel and a high nickel-chromium-iron alloy containing columbium

by T. N. Armstrong and W. L. Warner

CONSIDERABLE information has been developed over the past few years on the effect of low temperatures on the properties of steels. Sufficient knowledge has been gained on the influence of deoxidization practice, microstructure and composition to permit selection of steels that will retain the desired degree of toughness at temperatures as low as have been measured.

Although rapid strides have been made in low-temperature processing, and interest is growing in bulk storage of liquefied gases, the problem of low-temperature embrittlement has not been confined to extremely low temperatures, as the most frequent failures have been in equipment designed to operate at normal atmospheric temperatures, and a large portion of low-temperature processing has been conducted at temperatures between −40 and −160° F., temperatures at which ferritic steels have been used successfully.

The broad use of welding for joining components has added to the complexity of the problem, as properties in the base material adjacent to the weld are influenced by the procedure of welding. Also, when filler metal is used, the deposited metal must possess toughness of the same order as the base metal at the service temperature.

As study of properties of weld metal at low temperatures has been somewhat limited, it was decided to investigate the properties of deposited metal of ferritic nickel steel electrodes containing up to approximately 5% nickel. Tests were made on deposited metal from nine brands of commercial nickel steel electrodes with low-hydrogen-type coatings conforming to AMERICAN WELDING SOCIETY Classification XX15. A limited number of tests also were made on weld metal from Type 310 (25–20) stainless steel, a special Monel for welding steel and a special high nickel-chromium-iron alloy containing columbium, also designed for welding steel. The discussion in the first part of the paper is confined to tests of the ferritic nickel-steel electrodes which were made at the Watertown Arsenal Laboratory.

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DETAILS OF TEST

Each electrode was submitted to a performance test consisting of welding in the flat and vertical positions to determine the operating characteristics. Only the 5% nickel-steel electrode presented any difficulties. With this electrode, trouble was encountered with porosity and root cracking, although acceptable welds were finally obtained.

Butt welds, using $^3/_{16}$-in. electrodes, were made in the flat position on $1^1/_8$ in. low-carbon $3^1/_2$% nickel-steel plate conforming to A.S.T.M. Specifications A203 Grade D. Joint preparation consisted of a single V-groove with 60° included angle. A copper backing strip was used in all cases except for the 5% nickel-steel electrodes, which required a steel backing. Welds were made without preheat and a maximum interpass temperature of 300° F. was maintained. No cracking was encountered in either the plate or the welds except in the welds made with 5% nickel steel electrodes, as previously mentioned.

It is recognized that the electrode diameter was somewhat small for the thickness of plate, but the electrodes were procured before it was determined that plate thinner than $1^1/_8$ in. was at first not available. Approximately 18 beads were used in making each welds.

After X-raying the welded joints for soundness, sections were removed for preparation of all-weld metal tensile test specimens. Tensile tests were made on 0.505 in. all-deposited metal specimens from sections in the as-welded condition and after stress relieving at 1150° F. for 2 hr. The tensile specimens were machined from the top center portion of the weld to avoid plate dilution.

Chemical analyses were made on drillings taken from ends of broken tensile specimens. The analyses are listed in Table 1.

TENSILE TESTS OF DEPOSITED METAL

Results secured from test of all-weld metal are tabulated in Table 2.

In making the welds, the operator was permitted to select the current for each electrode that gave best performance characteristics. In some cases, the cur-

Table 1—Chemical Analysis of Deposited Metal

(Drillings Taken from One End of Broken Test Coupon)

Electrode	*Specimen*	*% C*	*% Mn*	*% Si*	*% Ni*	*% Cr*	*% Mo*	*% V*
A	A3	0.08	0.61	0.15	2.15	0.02	0.45	Nil
B	B1	0.12	1.11	0.29	2.72	0.02	0.03	Nil
C	C2	0.06	0.67	0.45	3.01	0.04	0.03	Nil
D	D1	0.08	0.80	0.69	2.70	0.10	0.03	Nil
E	E3	0.06	0.76	0.42	3.41	0.07	0.04	Nil
F	F2	0.065	0.80	0.23	3.58	0.01	0.02	Nil
G	G6	0.05	0.76	0.21	5.09	Nil	0.02	Tr
H	H1	0.07	0.79	0.19	3.55	0.03	0.02	Nil
J	J2	0.09	0.97	0.49	2.82	0.03	0.02	Nil
Plate	...	0.15	0.57	0.21	3.76	0.03	0.03	Nil

Analysis made on turnings from near center of all-deposited metal specimens. Welds were made on 1-in. plate.

rent was considerably below that recommended by the manufacturer and duplicate welds were made with higher current density. It was also evident that there was a difference in the moisture content of the coatings if the appearance of the fractured specimens could be accepted as the criterion. The following was recorded on condition of fracture.

There appears to be a closer relation between the condition of fracture and the reduction of area than between fracture and elongation, as the specimens with

Electrode	*Fracture appearance*
A	Partial cup—fibrous
B	One fracture irregular—other specimens fibrous
C	Partial cup—fibrous
D	Irregular—fine porosity and crystalline spots
DD	Partial cup—fibrous
E	Partial cup—fibrous
F	Cup—fibrous
G	Irregular—woody spots
H	Irregular—small crystalline spots
J	Irregular—crystalline spots—surface checks

Table 2—Tensile Test Data on All-Deposited Metal from Butt Welds in 1-In. Plate of 3½% Nickel Steel 3/16-In. Diam. Nickel Steel Electrodes

Rod	*Weld No.*	*Specimen*	*Amp.*	*V.*	*Yield, psi.*	*Tensile, psi.*	*Elongation in 2 in., %*	*Reduction of area, %*	*Condition*
A	A3	T1	160	20	76,250	91,750	22.0	63.0	A. W.*
		T2	160	20	76,250	91,750	22.5	62.7	A. W.
		T3	160	20	76,850	91,750	23.0	65.3	A. W.
	A5	T1	200	22	71,250	89,000	22.0	64.7	A. W.
	A6	T1	190	22	75,600	90,250	25.0	65.4	S. R.†
		T2	190	22	78,100	92,000	24.0	62.3	S. R.
B	B1	T1	160	20	80,000	96,750	18.0	43.0	A. W.
		T2	160	20	78,500	96,250	23.0	59.0	A. W.
	B2	T1	160	20	73,750	89,000	26.0	67.0	A. W.
	B3	T1	200	22	74,350	89,750	24.0	62.3	A. W.
	B4	T1	190	22	67,500	83,500	26.5	66.3	S. R.
		T2	190	22	68,750	83,750	26.0	65.1	S. R.
C	C1	T1	160	20	64,350	82,250	28.0	72.6	A. W.
	C2	T1	160	20	73,100	87,250	29.0	71.4	A. W.
		T2	160	20	72,500	85,750	26.0	68.5	A. W.
	C3	T1	180	27	61,850	81,750	28.5	65.6	A. W.
	C4	T1	190	23	66,250	82,000	27.0	64.7	S. R.
		T2	190	23	67,500	84,500	27.5	68.6	S. R.
D	D1	T1	160	20	83,750	97,750	15.0	29.4	A. W.
		T2	160	20	91,850	105,000	19.0	49.1	A. W.
	D2	T1	160	20	90,600	97,750	17.5	29.7	A. W.
	D5	T1	200	25	69,350	90,500	25.0	59.7	A. W.
	D7	T1	185	23	81,250	95,750	22.5	58.6	S. R.
		T2	185	23	88,100	102,000	22.0	54.6	S. R.
DD‡	D9	T1	190	24	82,500	100,000	23.0	60.3	A. W.
		T2	190	24	79,350	95,250	23.0	61.6	S. R.
E	E3	T1	160	20	66,250	87,000	28.0	69.7	A. W.
		T2	160	20	68,100	87,500	25.0	56.0	A. W.
	E4	T1	160	20	66,250	89,000	26.5	67.0	A. W.
	E6	T1	200	25	64,350	87,000	27.5	67.9	A. W.
	E8	T1	185	22	73,750	87,750	25.0	66.1	S. R.
		T2	185	22	75,000	89,500	25.0	67.0	S. R.
F	F2	T1	180	22	61,500	85,000	24.0	61.3	S. R.
		T2	180	22	75,000	89,250	26.0	64.5	S. R.
		T3	180	22	76,000	91,250	23.0	54.1	S. R.
G	G6	T1	170	22	83,000	91,000	9.5	22.6	S. R.
		T2	170	22	85,750	96,000	13.5	24.0	S. R.
		T3	170	22	83,750	95,500	18.5	39.7	S. R.
H	H2	T1	210	21	58,000	72,500	15.0	30.7	S. R.
		T2	210		56,750	73,000	24.0	43.3	S. R.
		T3	210		58,000	73,750	25.0	37.2	S. R.
J	J2	T1	220	20	66,250	81,250	19.0	36.6	S. R.
		T2	220	20	65,750	80,000	22.5	37.8	S. R.
		T3	220	20	65,000	79,000	20.0	34.0	S. R.

* A. W.—As-welded. † S. R.—Stress relieved at 1150° F. ‡ DD—Second lot of Electrode D.

Table 3—Welded Joint Tensile Tests ¾-In. Plate

(Flat Bars—Specimens As-Welded)

Electrode	*Mark*	*Area*	*Yield point, 1% Offset*	*Tensile strength*	*Elongation 2 in.*	*Break*
A	A4T1	0.438	57,100	82,100	19.5	P*
	A4T2	0.438	62,200	82,100	20.3	P
	A4T3	0.438	61,100	82,000	21	P
B	B1T1	0.5	63,000	84,200	20	P
	B1T2	0.5	61,500	84,800	19.5	P
	B1T3	0.5	59,000	84,400	19	P
C	C2T1	0.5	63,000	83,800	22	P
	C2T2	0.5	59,500	84,000	22	P
	C2T3	0.5	62,500	83,800	21.5	P
D	D1T1	0.5	66,500	84,600	16.5	P
	D1T2	0.5	61,000	85,200	17.5	P
	D1T3	0.5	59,500	85,600	15	Outside gage
E	E3T1	0.5	60,000	83,600	21.5	P
	E3T2	0.5	60,500	83,000	21.5	P
	E3T3	0.5	61,000	82,500	21	P
F	F2T1		56,800	78,000	25.5	P
	F2T2		58,800	77,400	26.0	P
	F2T3		54,400	77,400	26.0	P
G	G6T1		55,600	78,000	22.5	P
	G6T2		58,800	78,200	24.0	P
	G6T3		56,000	78,600	24.0	P
H	H2T1		56,000	76,400	22.0	W†
	H2T2		56,400	74,200	20.5	W
	H2T3		56,400	75,000	19.0	W
J	J2T1		57,000	79,000	25.5	P
	J2T2		57,200	79,000	25.0	P
	J2T3		57,900	79,000	26.5	P
Plate	BM1‡	0.5	53,000	79,600	34.5	
	BM2	0.5	57,000	79,600	35.0	
	BM3	0.5	57,500	79,800	34.5	

* P in plate outside transition zone. † W in weld metal. ‡ BM1, 2 and 3 unwelded base metal.

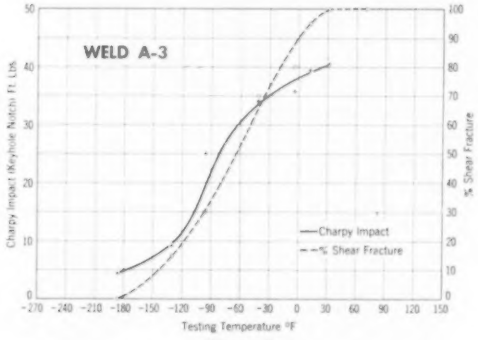

Figure 1

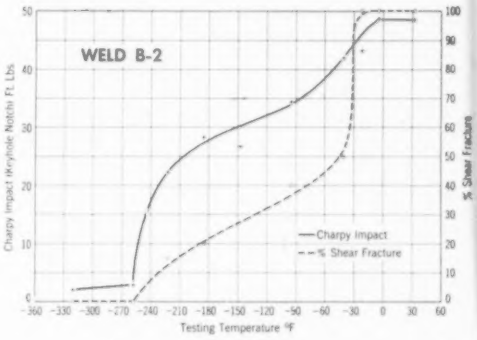

Figure 3

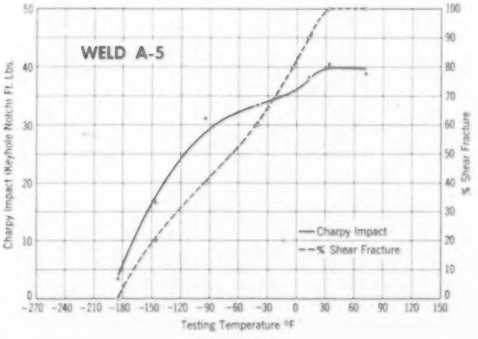

Figure 2

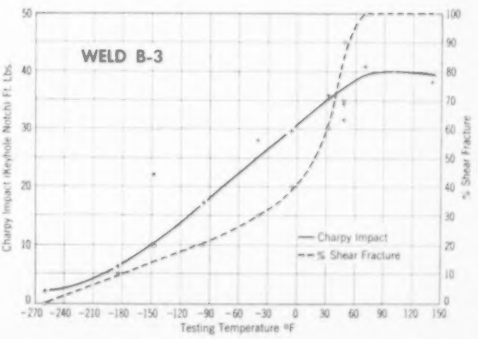

Figure 4

regular cup and cone fracture and fully fibrous all had high percentage of reduction of area. Elongation was not as much affected by small crystalline areas.

It is interesting to note the difference in strength values among the different welds, which appears to be due only in part to differences in analyses.

Stress relieving did not appear to affect the properties appreciably. This may be due to the large number of beads. If larger electrodes and fewer number of passes had been used, the difference between the properties in the as-welded condition and the stress-relieved condition might have been greater.

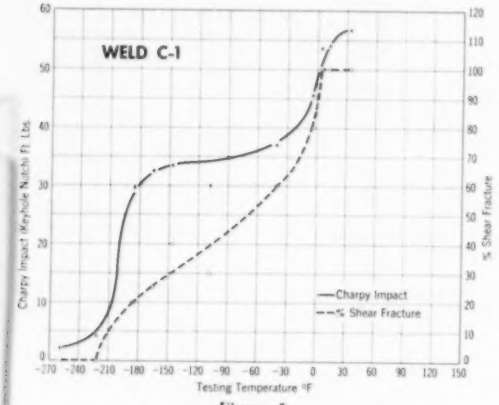

Figure 5

WELDED JOINT TENSILE TEST

The results of tensile tests of the welded joints are given in Table 3. These tests were made on plate 3/4 in. in thickness. In all cases, except for the welds made with electrode H, fracture occurred in the plate, which was to be expected, as strength properties of the welds were higher than those of the plate. Specimens welded with electrode H fractured in the welds.

These specimens were tested in the as-welded condition and tests of stress-relieved specimens were not made as it appeared that little additional information would be gained, since weld metal strengths were above plate strength except in one instance.

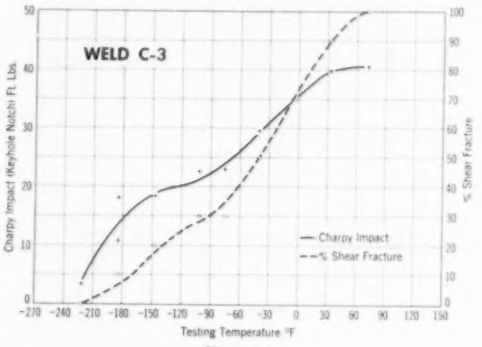

Figure 6

Table 4—Free Bend—Butt Welds

(Specimens 1 in. Thick by 1 1/2 in. Wide. All Specimens Stress Relieved at 1150° F. for 2 Hr.)

Electrode	*Weld*	*Specimen*	*Amp.*	*Elongation %*	*Remarks*
A	A4	B-1*	160	33.0	Separation in root pass below surface of specimen—questionable
		B-2†	160	31.0	O. K.—no cracks
A	A5	B-1	190	15.0	Large cracks at each edge of specimen
		B-2	190	33.0	Small tears at edges. Believed O. K.
B	B2	B-1	160	30.0	O. K.—no cracks
		B-2	160	31.0	O. K.—no cracks
B	B3	B-1	200	32.0	O. K. slight porosity in weld metal
		B-2	200	33.0	O. K.—no cracks
C	C1	B-1	160	30.0	O. K.—no cracks
		B-2	160	32.0	O. K.—no cracks
C	C3	B-1	180	28.0	Large crack across specimen in weld metal
		B-2	180	29.0	Porous spot in weld metal—questionable
D	D1	B-1	160	31.0	O. K.—no cracks
		B-2	160	31.0	Tear at one edge about 3/4 in. long. Believe O. K.
D	D5	B-1	200	17.0	Large crack at one edge in weld metal
		B-2	200	30.0	O. K.—porous spot in weld metal
E	E3	B-1	160	31.0	O. K.—no cracks
		B-2	160	30.0	O. K.—no cracks
E	E6	B-1	200	33.0	O. K.—small porous spot in weld metal
		B-2	200	31.0	O. K.—no cracks
F	F2	B-1	...	21.0	Cracks in weld metal
		B-2	...	30.0	No cracks
G	F6	B-1	...	11.0	Crack in weld metal
		B-2	...	31.0	Fine cracks in weld metal
H	...	B-1	...	12.2	Fine crack parallel to interface
		B-1A	...	30.5	No appreciable propagation of crack
J	...	B-2	...	30.0	Small tear in weld metal on side
		B-1	...	12.2	Fine crack at interface
		B-1A	...	23.6	No appreciable propagation of crack
		B-2	...	17.0	Fine crack in weld metal
		B-2A	...	31.0	No appreciable propagation of crack

* Specimens B-1 root bend. † Specimens B-2 face bend.

FREE BEND TESTS

Free bend tests, both root and face bends, were made on specimens stress relieved at 1150° F. Results are given in Table 4. In general, the origin of cracks appeared to be in nonmetallic inclusions, or in porous spots.

CHARPY IMPACT TESTS

Charpy impact specimens, with keyhole notch, were machined from butt welds made in 1¹/₈-in. plate. Test specimens were taken from the top half of the weld and transverse to the direction of welding. Specimens were notched perpendicular to the face of the weld, and all welds were stress relieved at 1150° F. for 2 hr. Specimens were tested at a series of temperatures between +175° and −238° F. In addition to recording energy absorption, the fracture of each specimen was observed, and the relative areas of fibrous and crystalline surfaces estimated. These data are plotted in Figs. 1 to 14, inclusive.

If 100% shear fracture is used as the criterion, it will be noted that this occurs for the different electrodes within a range of −30 to 120° F. The transition temperature is somewhat difficult to determine, as characteristic of nickel steel, there may not be a sharp break in the temperature energy absorption curve, but usually a gradual lowering of energy absorption occurs with decrease in temperature. An arbitrary comparison can be made in two ways: first, comparing impact values taken from the curves at temperatures of plus 70, 0 and −150° F., and second, comparing temperatures at which 15 ft.-lb. are obtained. For convenience these values are listed in the following table:

Weld	*Current, amp.*	*—Charpy impact, ft.-lb.— 70° F.*	*0° F.*	*−150° F.*	*Temperature, °F., for 15 ft.-lb. Charpy*
A3	160	43	36	7	−105
A5	200	40	36	16	−155
B2	160	48	48	30	−245
B3	200	40	30	10	−110
C1	160	58	48	34	−200
C3	180	41	36	18	−180
D2	160	28	26	12	−130
D5	200	35	21	19	−200
E4	160	44	37	26	−230
E6	200	44	36	27	−200
F1	180	36	31	7	−40
G7	170	27	21	6	−58
H2	210	44	39	23	−200
J2	220	42	36	24	−170

It appears that there may be an optimum welding current for each electrode to secure best low temperature properties, but C and E appear to be less affected by current density than A, B, and D. Electrodes F,

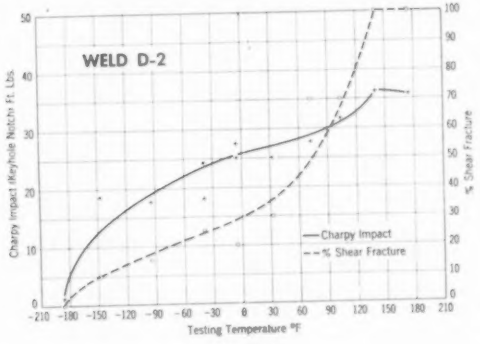

Figure 7

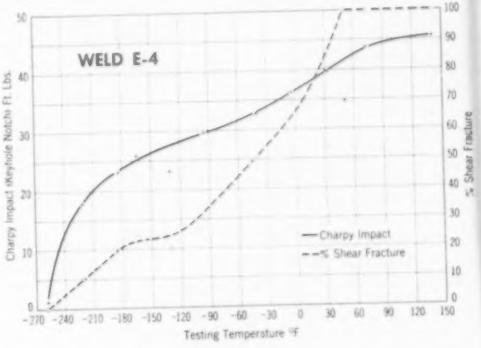

Figure 9

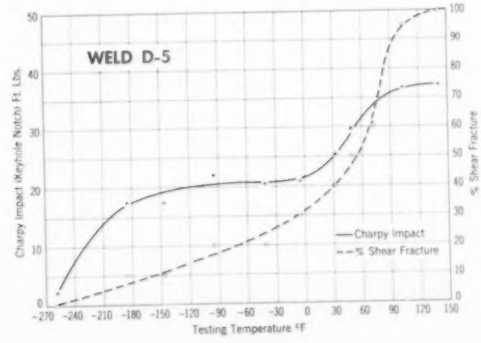

Figure 8

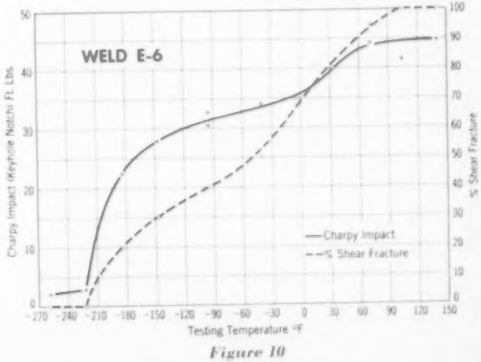

Figure 10

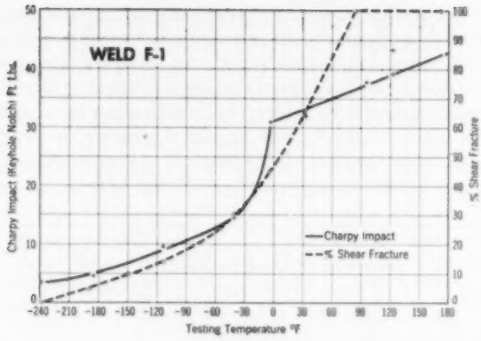

Figure 11

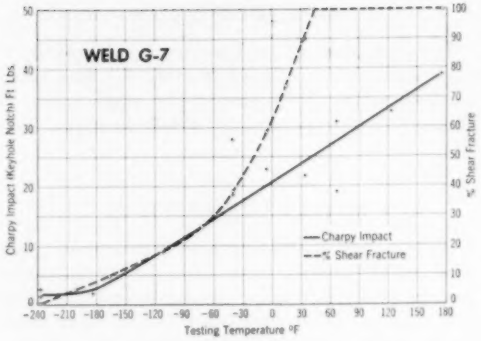

Figure 12

G, H and J were tested under only one condition of current. Electrodes H and J gave comparatively good results, but on the basis of both tensile properties and impact, electrodes F and G appear to be of questionable quality.

Impact tests were made on welds from two electrodes, A and E, at −65 and −150° F. to determine the effect of heat treatment. The results are shown in the following table:

Effect of Heat Treatment on Low Temperature Impact Properties

Condition	*Charpy impact, ft.-lb., ° F.* −65	−150	*% Fibrous fracture, ° F.* −65	−150
	Electrode A			
As-welded	31, 34	28, 29	70	50
Stress relieved, 1150° F.	29, 32	7, 16	50	4, 10
Normalized, 1600°; stress relieved, 1150° F.	41, 42	31, 35	60	20
Water quenched, 1600°; stress relieved, 1150° F.	37, 38	29, 30	60	20
	Electrode E			
As-welded	41, 42	31, 34	70	35
Stress relieved, 1105° F.	31, 32	26, 27	45	22, 30
Normalized, 1650°; stress relieved, 1150° F.	35, 36	39, 31	50	25
Water quenched, 1160°; stress relieved, 1150° F.	33, 34	26, 27	50	20

It is surprising that heat treatment does not effect an appreciable improvement. In fact, the stress-relieved specimens are appreciably lower at −150° F. than the as-welded specimens. Also, normalizing and stress relieving is preferred to water quenching and stress relieving.

There is a remote possibility that the stress-relieved specimens are affected by temper embrittlement, but it should be recognized that Electrode A, which suffered more deterioration in properties than Electrode E on stress relieving, contained 0.45% molybdenum.

CRACKING SENSITIVITY TEST

Electrodes A and B were submitted to a cracking sensitivity test, called the patch test, developed by the U. S. Navy Dept. The plate was 1 x 12 x 12 in., rather than the recommended 24 in. square, which was reported to cause greater restraint. Welds from neither electrode cracked when the quadrants were welded at 150 and at 70° F. Welds were not made at lower temperatures, which is considered to introduce greater restraint.

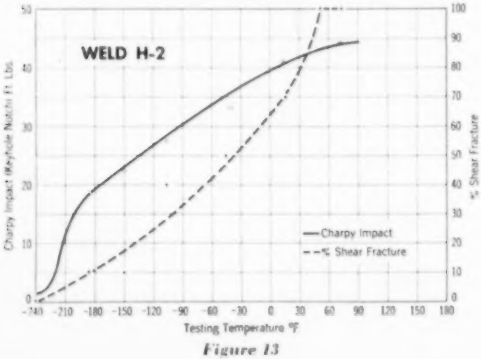

Figure 13

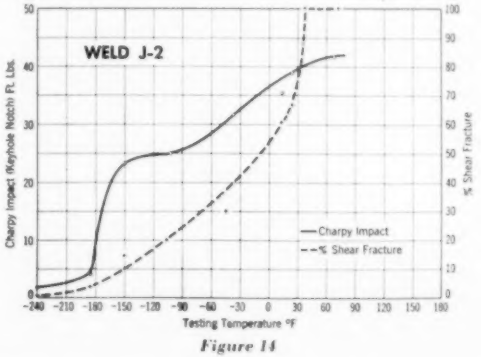

Figure 14

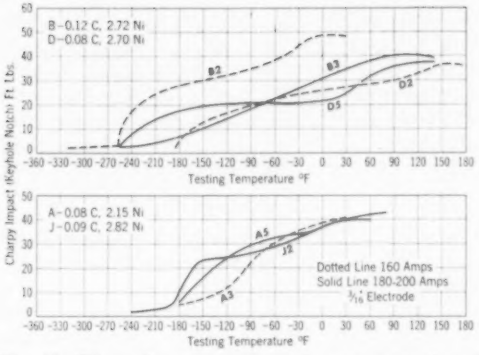

Fig. 15 Effect of temperature on impact properties of weld metal containing less than 3% nickel

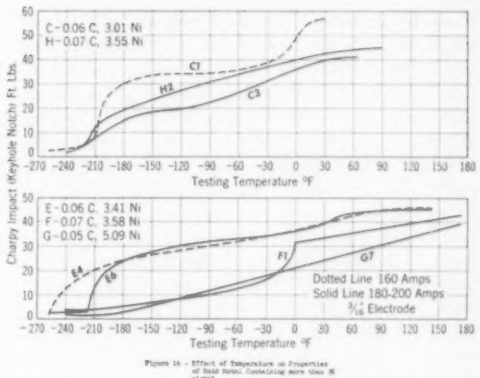

Fig. 16 Effect of temperature on properties of weld metal containing more than 3% nickel

HIGH-ALLOY ELECTRODES

Standard U-groove butt welds were made on plate of low-carbon 9% nickel steel with each of the three high-alloy electrodes; namely, Type 310 (25 Cr–20 Ni) stainless steel, a special Monel for welding on steel designated as 140 Monel, and an 80% nickel-chromium-iron alloy containing columbium designated as R38C. All weld metal tensile specimens were taken from the top half of the weld. Weld joint tensile tests were taken transverse to the direction of welding and tests made on both as-welded and stress relieved (1050° F. for 2 hr.) specimens. Results of tests from all-deposited metal specimens were as follows:

Tensile Test Results of All-Deposited Metal, High-Alloy Electrodes

Electrode	*Tensile strength, psi.*	*Yield point, psi.*	*Elongation % in 2 in.*	*Reduction of area, %*
310 Stainless	87,500	55,000	38.0	52.0
140 Monel	82,000	45,000	37.0	51.0
R38C (80% Ni)	102,000	59,000	24.0	...
R38C (reheated 1050°)	109,000	68,500	33.0	...

Welded Joint Tensile Tests

Type, weld and condition	*Tensile strength, psi.*	*Yield strength, psi.*	*Elongation % in 2 in.*	*Reduction of area, %*	*Location of fracture*
Type 310, as-welded	86,500	52,000	7.0	18.0	Weld
R38C, as-welded	88,000	68,000	5.0	19.0	Weld
R38C, stress relieved	108,500	67,000	27.0	59.0	Plate
140 Monel, as-welded	85,000	55,800	8.0	27.5	Weld
140 Monel, stress relieved	96,300	74,000	8.0	19.5	Weld

Stress relieved at 1050° F.—low ductility values due to all deformation occurring in weld metal except in one specimen that broke in plate.

These results indicate that both 140 Monel and R38C are subject to precipitation hardening at the temperature of stress relieving. Welds from either electrode would meet a yield strength requirement of 65,000 psi. after stress relieving. Previous tests indicated welds of Type 310 were unaffected by stress relieving.

IMPACT PROPERTIES OF HIGH-ALLOY WELDS

Impact specimens were machined with the notch at the approximate center of the weld and parallel to the plate surface. Specimens were tested at 70 and at −320° F. Results were as follows:

Charpy Impact Results on High-Alloy Welds (Keyhole Notch)

	Charpy impact, ft.-lb., ° F.	
Type, weld and condition	*70*	*−320*
Type 310 Stainless, as-welded	29	22
R38C, as-welded	27	31
R38C stress relieved, 1050° F.	29	29
140 Monel, as-welded	35	35
140 Monel, stress relieved, 1050° F.	28	28

These results indicate that increase in strength of R38C and 140 Monel welds due to stress relieving is not accompanied by a significant decrease in notched-bar impact properties. There was some decrease in the notch toughness of the stainless steel weld with decrease in temperature but the R38C and 140 Monel welds were not affected.

CONCLUSION

The results indicate that low temperature impact

properties sufficient to meet requirements of most commercial specifications can be obtained at temperatures down to below −150° F. in weld metal deposited from some commercial nickel steel electrodes with low-hydrogen types of coatings. There are significant differences in both normal temperature tensile properties and low-temperature impact properties of weld metal deposited from different brands of electrodes which are due, in part, to factors other than composition. Also, properties of the weld metal are affected more by change in welding current with some electrodes than with others. Properties of all-weld metal in welds $^{3}/_{4}$ to $1^{1}/_{8}$ in. thick were not improved by stress relieving. Most of the nickel steel electrodes tested would conform to AMERICAN WELDING SOCIETY, Classification E 8015.

Impact properties of welds made with two different types of high nickel alloy electrodes suitable for welding ferritic steels did not appear to be affected by temperatures as low as −320° F. Although impact properties of weld metal from Type 310 stainless-steel electrode were lower at −320° F. than at 70° F., values were sufficiently high to meet requirements of most specifications.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of the members of the staff at the Watertown Arsenal Laboratory who conducted the tests of the ferritic nickel steel electrodes. The tests on the high-alloy welds were performed under the direction of T. E. Kihlgren of the International Nickel Co., Research Laboratory.

The statements and opinions appearing in this paper are those of the authors' and do not necessarily reflect the views of the Army Ordnance Department.

A Torsion Test for Spot Welds*

THE torsion test specimen and machine shown in Figs. 1 and 2 have been found useful in developing spot-welding procedures for steels having a tensile strength of 64,000 psi. (0.25% carbon) used in railway car construction. The specimen is not affected by buckling of the sheets. The angle of twist provides

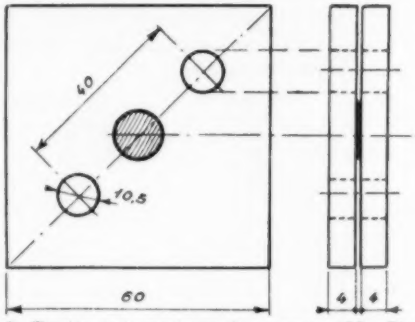

Fig. 1 Torsion test specimen for a spot weld. Dimensions in millimeters

a useful measure of the ductility of the weld. The sensitivity of the test is illustrated by the test curves, Fig. 3, drawn by the machine. The welding cycle is shown below each curve. The welding current I_r was 16,500 amp. in each test, and the preheating current was approximately 11,000 amp. The weld was quenched under the electrodes and then was reheated by currents increasing from 13,500 amp. in Diagram F to 16,500 amp. in Diagram A. Best results are indicated in C and D. Weld A was overheated while Weld F was not heated to the proper temperature for annealing.

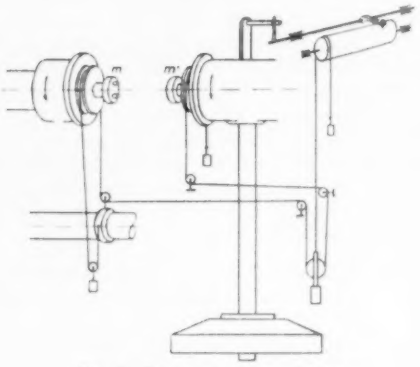

Fig. 2 Torsion testing machine

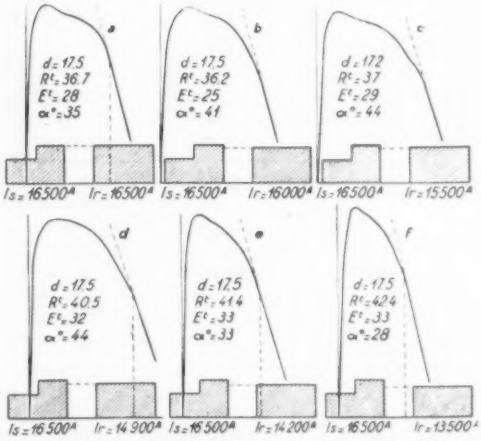

Fig. 3 Torion test diagrams for spot welds 0.69 in. diameter in mild steel sheets

E_t = elastic limit in torsion, kg./mm.^{2}; R_t = ultimate strength in torsion, kg./mm.^{2}; α = angle of twist at failure, degrees; vertical axis = load; horizontal axis = angle of twist.

* Abstract of an article by R. Biais entitled "Contribution à l'étude de la Qualité des soudures par points," published in *Soudure et Techniques Connexes*, 3, pp. 189–202 (Sept.–Oct. 1949). (Abstracted by Dr. G. E. Claussen.)

Brittle Failure and Size Effect in a Mild Steel

Within limits and with due regard to fracture criteria specimen size does not affect transition temperature. A modified Charpy-type impact bar is suitable for fracture transition studies

by K. J. Stodden and E. P. Klier

Abstract

It has been generally accepted that the physical properties of mild steels are highly affected by the size of the test specimen. Thus with reference to the inception of brittle failure, it is believed that for increasing specimen size the temperature is increased at which brittle failure may be encountered. Assuming the validity of this interpretation of size effect, it is evidently very difficult to rationalize (say) service behavior of a mild steel with small-scale test results.

In the present work an effort is made to show that under certain experimental conditions the phenomenon of size effect can be sensibly eliminated as it pertains to the appearance of brittle failure. The specimen sizes studied ranged from the 10- x 10-mm. Charpy bar to a $1^1/_4$- x $1^1/_4$-in. bar tested in slow bending. For these specimen sizes the transition temperature for a mild steel was invariant.

INTRODUCTION

IT WAS recognized at a very early date that the fracture characteristics of a steel, as revealed in the Charpy-type impact test, were dependent on the width of the test bar.[1-5] Energy absorption curves, reduced to a constant cross section, frequently indicated, as in Fig. 1, that as the specimen width increased a transition from a ductile to a brittle fracture took place. The critical width at which this transition was effected for a given steel was determined by the temperature of the test. Other factors which are important in determining this transition for a given steel are the testing velocity,[1, 5] the notch root radius [6, 7] and the cross-section height.[8] Of these factors the effects of variations in specimen width have been most extensively studied.

With respect to the effect of notch diameter on the fracture phenomena for a given steel, it is known that as the notch becomes increasingly acute, the transition from ductile to brittle behavior is raised to higher temperatures, but it is evident that the elevation of the transition temperature by this factor must be limited. Thus for a given steel and given test specimen size there is probably a temperature above which ductile fractures are obtained even for the sharpest notch.

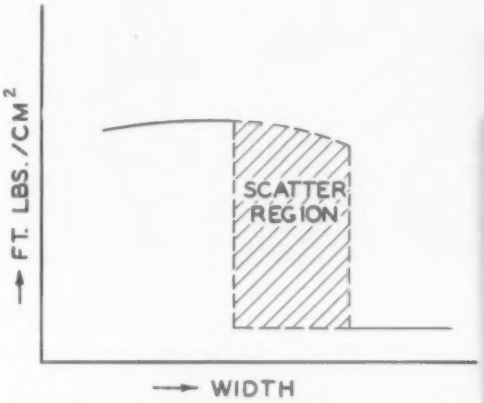

Fig. 1 Schematic illustration of specific impact work vs. specimen width at constant testing temperature

There is adequate evidence that on increasing the testing velocity the transition in fracture phenomena takes place at higher temperatures,[5] and it is probable that an increase in the test specimen height produces the same effect.

In an examination of "size effect," reasonable control must be exercised over notch radius and testing velocity, if variations in fracture behavior are to be isolated and attributed to dimensional changes of the test bar. But such control may be difficult to achieve, in so far as the notch root radius is concerned. Thus, as the notched bar is loaded, failure is initiated at the base of the notch, and this crack being much sharper than the original notch serves as the effective notch. By classical elasticity theory this would mean more unfavorable notching conditions for the larger test bars,[9, 10] but according to Neuber[11] this difficulty may be minimized.

According to Neuber[11] notch action must have a

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The work presented here comprises a thesis submitted by Mr. Stodden under the supervision of Dr. Klier in partial fulfillment of the requirements for the degree of Master of Science.

Presented at the Thirtieth Annual Meeting, A.W.S., Cleveland, Ohio, week of Oct. 17, 1949.

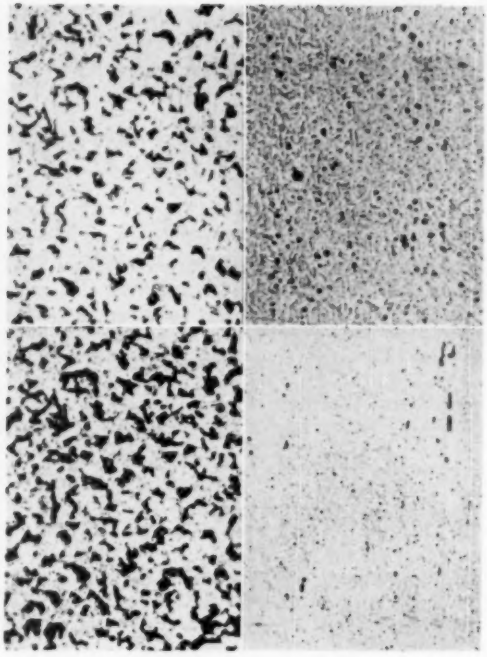

Fig. 2 Microstructure and inclusions in the transverse direction. 100×

limiting severity, and this limiting condition is characteristic of the material. For steels this leads to the suggestion that the limiting "sharp" notch is one having a root radius of approximately 0.019 in., and if the test specimens are notched with a notch of this root radius, the notch effect will be reasonably constant for all specimens. The testing conditions for the different size specimens will not be fully comparable, however, as the stress gradients in the test section will vary. This variation in stress gradient could be expected to become increasingly important as the specimen size is decreased.

In the present report the slow-bend test previously discussed[12] is used to study the effect of size of test bar on the fracture characteristics of a mild steel. The testing velocity has been held sensibly constant while a 0.0015-in. root radius pressed notch, which it is believed attains Neuber's limiting notch size for this steel, has been used for all slow-bend specimens.

Fig. 3 Microstructure and inclusions in the direction of rolling. 100×

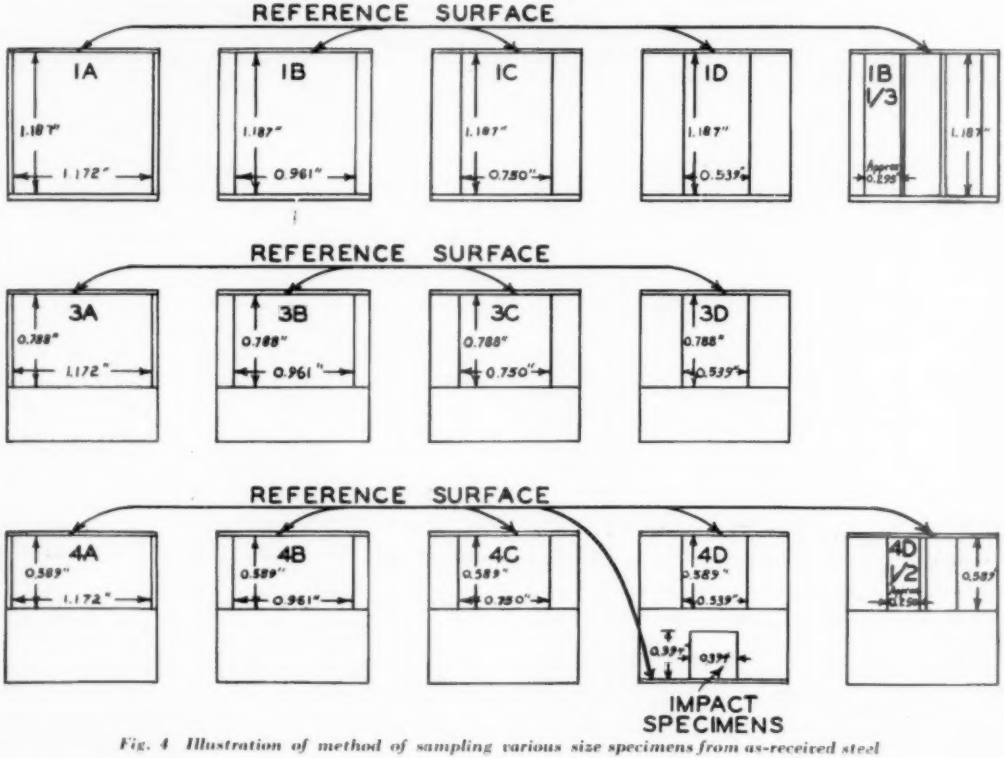

Fig. 4 Illustration of method of sampling various size specimens from as-received steel

EXPERIMENTAL PROCEDURE

Steel: The semi-killed C-1023 steel, which was studied, gave for the ladle analysis C 0.21, Mn 0.43, P 0.014 and S 0.040. This steel was furnished as hot-rolled $1^1/_2$-in. sq. bar stock. All steel studied was rolled from the same billet. Typical microstructures are presented in Figs. 2 and 3.

Specimen Preparation: The bar stock was supplied in sections 6 ft. long. These bars were cut into $11^1/_2$-in. lengths which were sawed and shaped to the cross sections indicated in Fig. 4. Approximately 30 specimens of each size were prepared. The final specimen dimensions are indicated in Fig. 5. The notch is the 0.0015-in. root radius pressed notch described by Bagsar.[12] After the slow-bend specimens indicated in Fig. 5 had been tested, it appeared advisable to test specimens of less width. Two sets of specimens designated $4D^1/_2$ and $1B^1/_2$ were prepared as follows: 4D specimens were sawed in halves to give $4D^1/_2$ specimens; while 1B specimens were sawed into thirds to give $1B^1/_2$ specimens. The $4D^1/_2$ specimens were approximately 0.25 in. wide, while the $1B^1/_2$ specimens were approximately 0.30 in. wide. The sawed surfaces were not further machined. A limited number of Charpy bars—designated VPD below—were also tested.

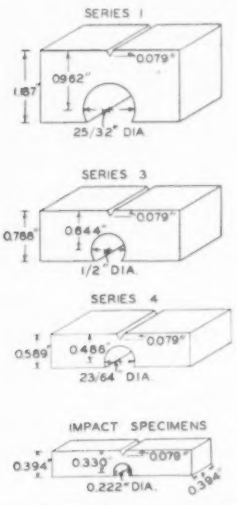

Fig. 5 Final specimen specifications for each height

In addition to the slow-bend test bars, five sets of Charpy impact test bars were prepared as follows:

(*a*) Standard Charpy key-hole notch (KH designation).

(*b*) Standard Charpy 0.01-in. root radius V-notch (VM designation).

(*c*) Standard Charpy 0.0015-in. root radius pressed V-notch (VP designation).

(*d*) Specimen in (*b*) Schnadt modification (VMD designation).

(*e*) Specimen in (*c*) Schnadt modification (VPD designation).

The impact specimens were all finished by grinding.

Representation of Test Data: The data consisting of lateral contraction,* fracture type and maximum load measurements are reported graphically. Pertinent numerical data are tabulated.

* This representation of the ductile-brittle transition has been discussed at length.[12] It is sufficient to point out here that the measurements reported in this investigation were made at the pin location in the test section.

EXPERIMENTAL RESULTS

Impact Tests: In order that the fracture characteristics of the steel studied might be classified more fully, the standard impact tests were conducted. The results for the standard Charpy key-hole notch specimen are presented in Fig. 6, and in Table 1.

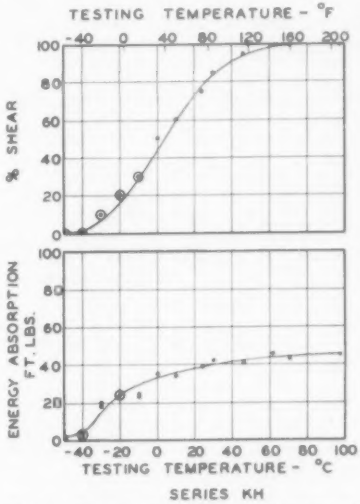
TESTING TEMPERATURE - °F
-40 0 40 80 120 160 200
% SHEAR
0 20 40 60 80 100
ENERGY ABSORPTION FT. LBS.
0 20 40 60 80 100
-40 -20 0 20 40 60 80 100
TESTING TEMPERATURE - °C
SERIES KH

Fig. 6 Energy absorption and fracture appearance vs. testing temperature for standard keyhole-notch Charpy impact specimens

Table 1—Transition Temperatures Obtained for Charpy Impact Specimens of Varying Types Determined by the Listed Criteria

	Transition temperature, °F.		
Type of specimen	*Temperature of $^1/_2$ max. energy absorption*	*Temperature of 50% shear*	*Temperature of $^1/_2$ max. lateral contraction*
Keyhole notch	−8	39	...
V-notch (milled)	86	95	...
V-notch (pressed)	−35	124	...
V-notch (milled) Schnadt modification	80	88	64
V-notch (pressed) Schnadt modification	127	127	127

The transition in energy absorption—taken at 50% maximum energy absorption—lies at from −10 to −5° F. The transition in fracture appearance—taken at 50% fibrous fracture—lies at +40° F. Despite this difference in transition temperature, if the upper limit of the energy absorption transition range be taken as that temperature at which the first drop off in energy absorption occurs, this limit is in good agreement with that given by fracture appearance. The lower limits of both transition ranges are at −40° F.

The results for the standard Charpy V-notch specimen with notch radii of 0.01 and 0.0015 in., respectively, are presented in Fig. 7 and in Table 1.

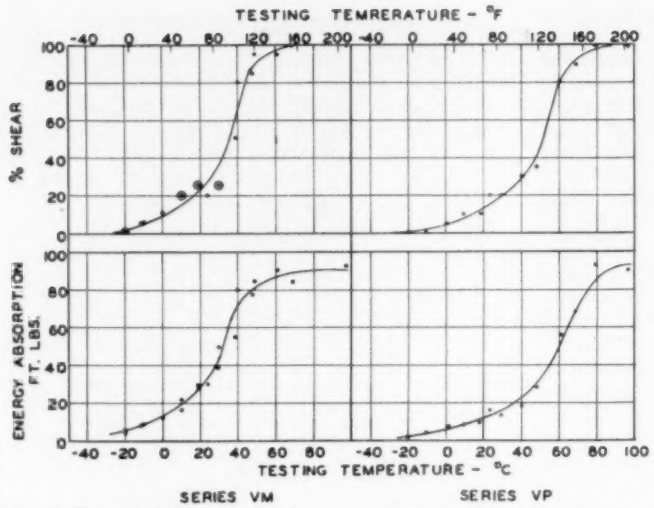

Fig. 7 Energy absorption and fracture appearance vs. testing temperature for V-notch milled and V-notch pressed Charpy impact specimens

The transition in fracture appearance conforms closely to the transition in energy absorption for both notch radii. This is true not only for the half maximum points on the comparable curves, but is true also for the comparable transition curves throughout the respective transition ranges.

In a comparison of the transition data for the two notch radii, it will be noted that the specimen with the 0.0015-in. root radius notch has the higher transition temperature at 50% maximum energy absorption. Zeno and Low[14] in a comparison with the results for a standard 0.01-in. root radius notch specimen, observed a comparable elevation in this temperature for a specimen possessing a fatigue crack as the effective notch. It would seem, therefore, that the fatigue crack and the pressed notch give about equivalent notch action.

The results obtained for the standard Charpy V-notch specimen, Schnadt modification with notch root radii of 0.01 and 0.0015 in., respectively, are presented in Fig. 8 and in Table 1.

The transitions in per cent ductile fracture, energy absorption* and lateral contraction are in close agreement for the specimen with 0.0015-in. root radius pressed notch. For the specimen with 0.01-in. root radius milled notch the transition in lateral contraction is not in full agreement with the transition in per cent ductile fracture and energy absorption. The transition temperatures taken as the 50% of maximum location on the curves, however, are sufficiently close to be considered as comparable criteria of transition from ductile to brittle behavior.

It is important to note, finally, that the transition from ductile to brittle behavior for the standard Charpy specimen, Schnadt modification, is accomplished in a very short temperature interval, with the exception of the transition in lateral contraction for the specimen

* The value of the energy absorption measurements is minimized because of jamming of the specimens.

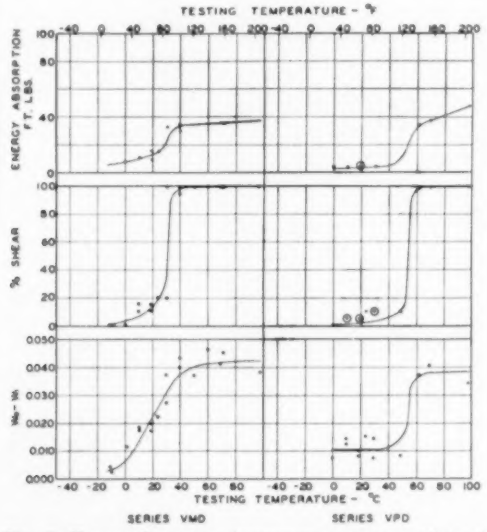

Fig. 8 Energy absorption, fracture appearance and lateral contraction vs. testing temperature for V-notch milled (Schnadt modification) and V-notch pressed (Schnadt modification) Charpy impact specimens

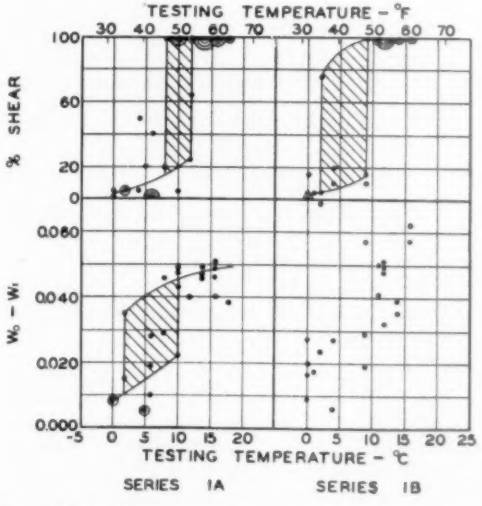

Fig. 9 Lateral contraction and fracture appearance vs. testing temperature for slow-bend series 1A and 1B

with the 0.01-in. root radius milled notch. With this exception it is possible to speak of a transition temperature without the necessity of referring to a transition range. The temperatures of transition from ductile to brittle behavior for the V-notch specimens are in satisfactory agreement for the respective notch radii for the standard and Schnadt modification Charpy bars.

Slow-Bend Tests: The slow-bend test data are plotted in Figs. 9–16. Temperatures of transition from ductile to brittle behavior taken from these curves are plotted in Figs. 17–20. Pertinent numerical values are also assembled in Table 2.

In a consideration of Figs. 9–16 it is evident that both fracture type and lateral contraction measurements are for the most part in satisfactory agreement in indicating the transition in fracture characteristics. Both of these criteria reveal temperature ranges in which the transition is accomplished, but these are quite narrow (less than 10° C.) with one exception where the transition range is 15° C. wide. It is evident that no appreciable error arises from the selection as the transition temperature of that highest temperature at which brittle failures are encountered.

The steel which was tested appears to have been

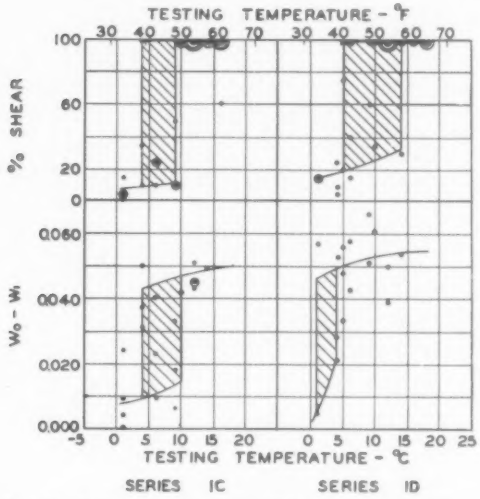

Fig. 10 Lateral contraction and fracture appearance vs. testing temperature for series 1C and 1D

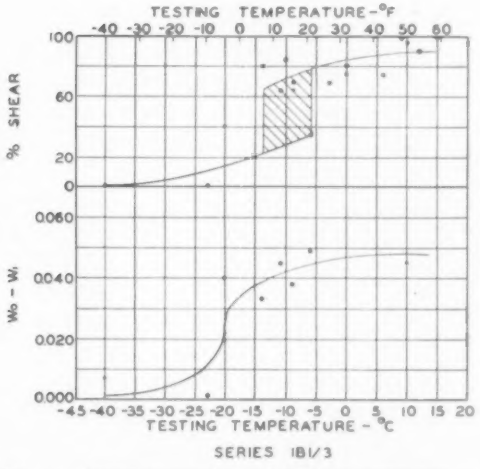

Fig. 11 Lateral contraction and fracture appearance vs. testing temperature for series 1B1/3

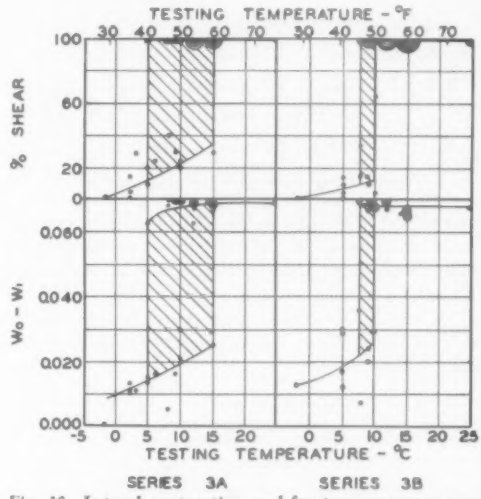

Fig. 12 Lateral contraction and fracture appearance vs. testing temperature for series 3A and 3B

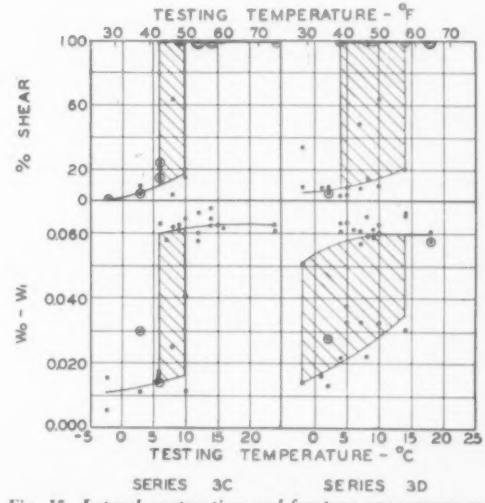

Fig. 13 Lateral contraction and fracture appearance vs. testing temperature for series 3C and 3D

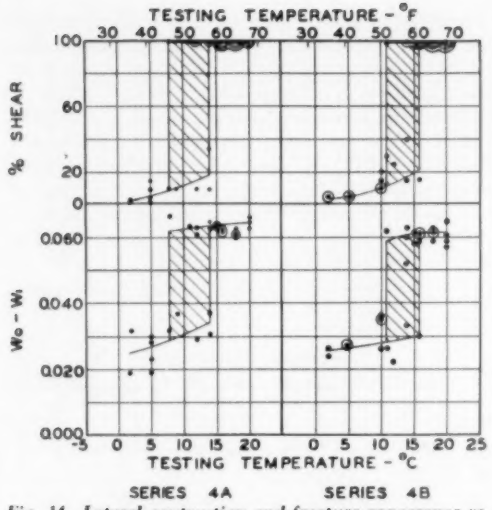

Fig. 14 Lateral contraction and fracture appearance vs. testing temperature for series 4A and 4B

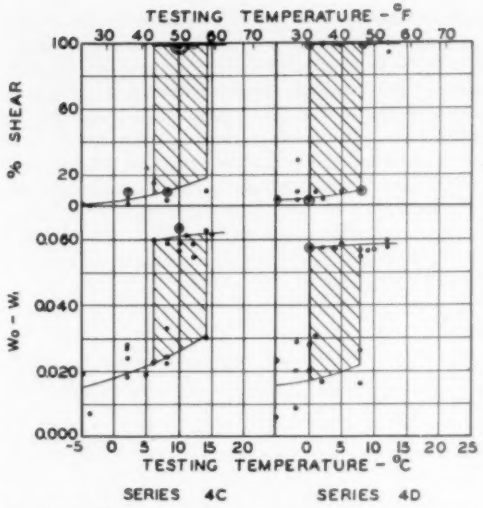

Fig. 15 Lateral contraction and fracture appearance vs. testing temperature for series 4C and 4D

homogeneous. Specimens (Size 3C) selected at random through the stock did not reveal any inhomogeneity during testing. It is probable that the fracture characteristics vary slightly from one end of the billet to the other, but the transition from ductile to brittle behavior appears established within the temperature range +10 to +15° C.

Table 2—Transition Temperature for Various Size Slow-Bend Specimens

Specimen designation	Temperature of 50% shear at upper limit of range of scatter, °C.	°F.
1A	12	54
1B	9	48
1C	9	48
1D	14	57
1B½	−6	21
3A	15	59
3B	10	50
3C	10	50
3D	14	57
4A	14	57
4B	16	61
4C	14	57
4D	8	46
4D½	3	37
VPD	9	48

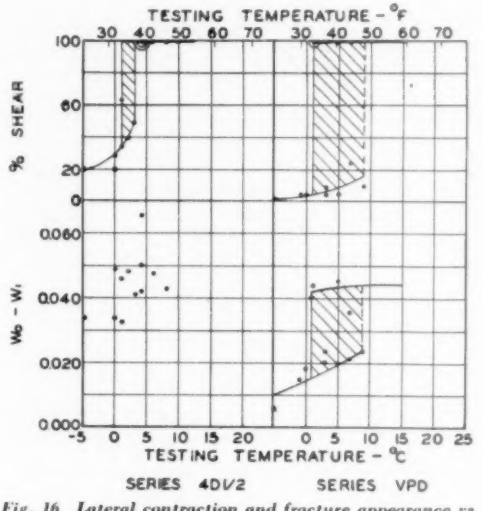

Fig. 16 Lateral contraction and fracture appearance vs. testing temperature for series 4D ½ and VPD

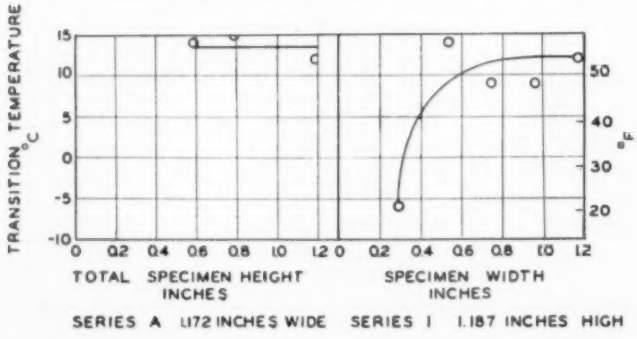

Fig. 17 Transition temperature vs. specimen height for series A and specimen width for series I

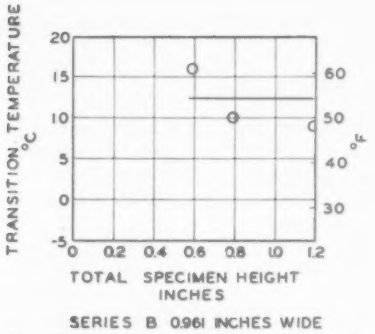

Fig. 18 Transition temperature vs. specimen height for series B

From Figs. 17–20 it is evident that the transition from ductile to brittle failure takes place at a nearly constant temperature for the specimen dimensions studied. Only for the smallest specimens does there appear to be a lowering of the transition temperature. The specimens in sizes 1B$^1/_2$, 4D$^1/_2$ and VPD were tested in an attempt to establish definitely any trend indicated by the data for Specimen 4D, and also to establish if any such trend resulted from a reduction of width or height.

The results obtained with these last three sets of specimens indicate that the transition temperature given for the Specimens 4D is not lower than might be expected from material variations of the bar stock studied. This is especially emphasized by the results obtained on Specimens VPD, which despite the reduction in cross section give an indicated transition temperature comparable with that for Specimens 4D.

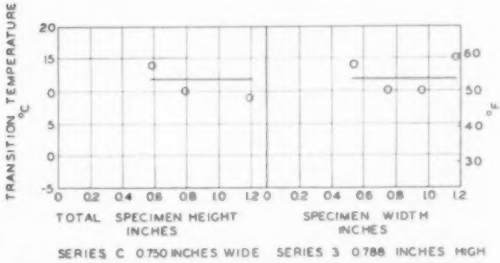
TRANSITION TEMPERATURE °C
°F
TOTAL SPECIMEN HEIGHT INCHES
SPECIMEN WIDTH INCHES
SERIES C 0.750 INCHES WIDE SERIES 3 0.788 INCHES HIGH

Fig. 19 Transition temperature vs. specimen height for series C and specimen width for series 3

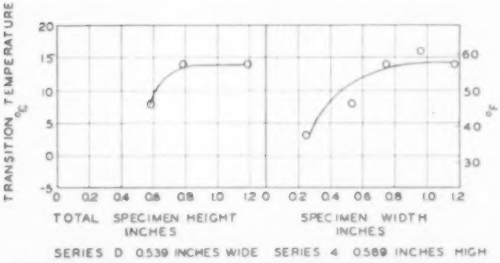
TRANSITION TEMPERATURE °C
°F
TOTAL SPECIMEN HEIGHT INCHES
SPECIMEN WIDTH INCHES
SERIES D 0.539 INCHES WIDE SERIES 4 0.589 INCHES HIGH

Fig. 20 Transition temperature vs. specimen height for series D and specimen width for series 4

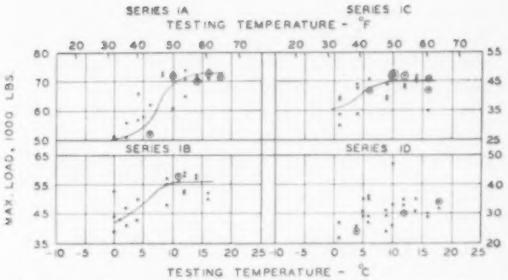

Fig. 21 Maximum load during test vs. testing temperature for series 1A, 1B, 1C and 1D

The lowering of the transition temperature and the alteration in the transitional behavior indicated for Specimens 1B $^1/_2$ and 4D $^1/_2$, may be attributed to the change in specimen width. This conclusion in conjunction with the results of Zeno and Low [14] on the effects of the depth of a fatigue crack on the transition temperature indicates that "size effect" probably cannot be eliminated in fracture studies for specimens smaller than the standard Charpy V-notch specimen.

Bagsar[13] has used as a criterion of transition from ductile to brittle failure the maximum nominal load sustained by the test section. Maximum load values obtained in slow-bend testing are plotted in Fig. 21 to 23.

In keeping with Bagsar's findings these data, for the most part, reveal a drop off in the maximum load

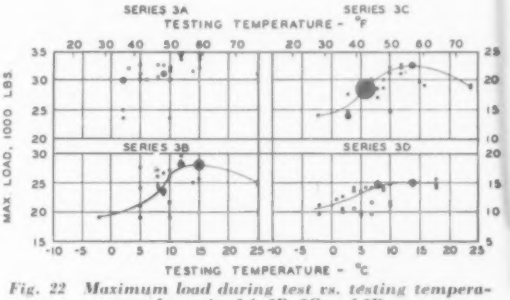

Fig. 22 Maximum load during test vs. testing temperature for series 3A, 3B, 3C and 3D

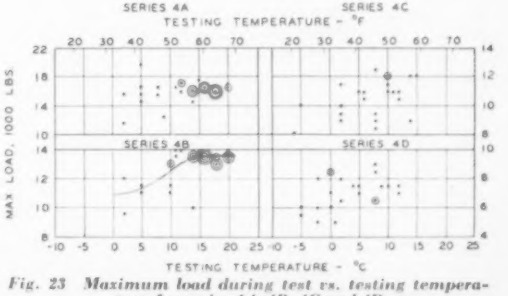

Fig. 23 Maximum load during test vs. testing temperature for series 4A, 4B, 4C and 4D

through a transition range corresponding to the ductile-brittle fracture transition. For this test procedure the transition in load values is not a sensitive index of the ductile-brittle transition.

A comparison of the reduced moment for the various specimens reveals no size effect, but there is little question that were it possible to compare the energies absorbed to fracture, a size effect would be found.[10]

DISCUSSION AND CONCLUSIONS

In the consideration of the fracture phenomena encountered in mild steels, it is known that the criteria of the ductile-brittle transitions do not in general agree.[12] Thus the change from a shear to a cleavage type fracture may occur at a much higher temperature than does the transition in energy absorption for a given test. However, both transition criteria are widely used in the evaluation of mild-steel plate.[17, 18]

In the evaluation of "size effect" for a given steel the selection of a criterion of the ductile-brittle transition becomes of major importance, and it is obvious that if a test procedure exists for which these criteria are in adequate agreement, an important source of confusion in the interpretation of results will have been eliminated. The slow-bend test, as used here, appears to be a test for which this agreement in transition criteria is largely achieved. For this test bar and for the steel examined, therefore, it is possible to speak of a transition temperature which is largely independent of specimen size, so long as the transition criteria are in full agreement. The transition temperature determined here may then have a fundamental significance in the evaluation of notch sensitivity, and may be properly compared to a comparable temperature obtained for another steel.

In a comparison of this sort an additional factor may readily be evaluated, and this is a velocity of loading factor. Thus the transition temperature is elevated with increasing loading rate. The rate of increase in the transition temperature unquestionably varies from steel to steel, and is undoubtedly an important quantity. If the "size effect" is satisfactorily eliminated for a given steel, the velocity effect may be studied directly.

The transition data are possibly significant in one other direction, and this is the evaluation of the test results of non-standard fracture test bars. For such test bars, so long as the fracture criteria are in full agreement, the transition data may for practical purposes be consistent with the fracture data obtained with a standard test.

SUMMARY

1. It has been shown that for the steel studied the specimen size, within the limits discussed, has no effect on the temperature of transition from ductile to brittle behavior so long as the transition criteria are in suitable agreement.

2. The Charpy-type impact bar when tested in the Schnadt modification gives a transition in fracture characteristics which is very sharp. This makes this test bar particularly suitable for fracture transition studies.

ACKNOWLEDGMENT

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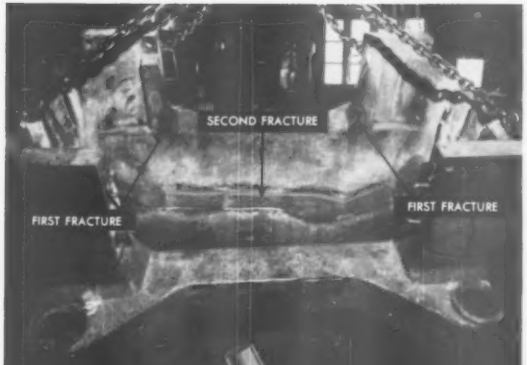

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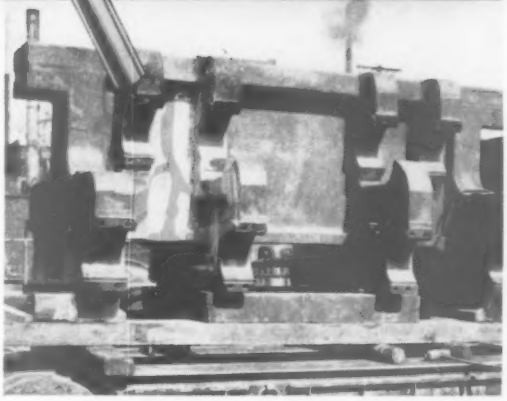

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